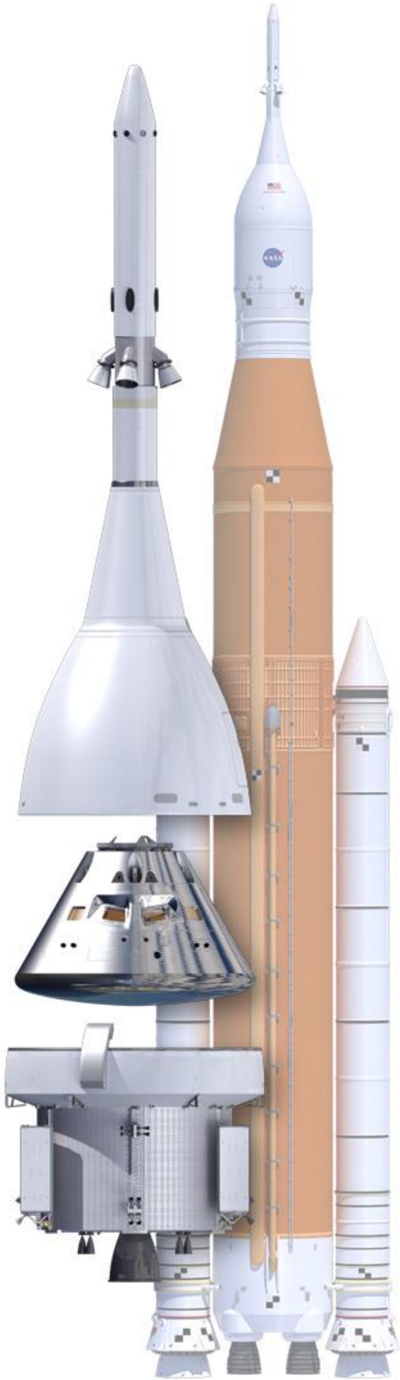


Orion @ Ames

Parul Agrawal

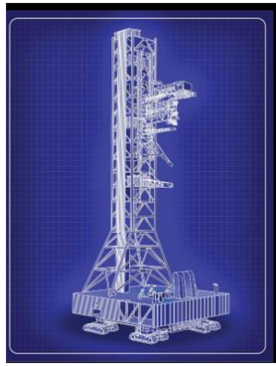
August 2022

Artemis Mission Objectives

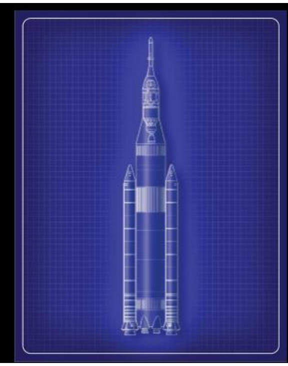
- With Artemis missions, NASA will establish the first long-term presence on the Moon. The exploration and settlement on Moon will enable the next giant leap - sending the first astronauts to Mars

- The primary goal of Artemis I is to thoroughly test the integrated systems by launching Orion atop the SLS rocket, operating the spacecraft in a deep space environment, testing Orion's heat shield, and recovering the crew module after reentry, descent, and splashdown before crewed missions.

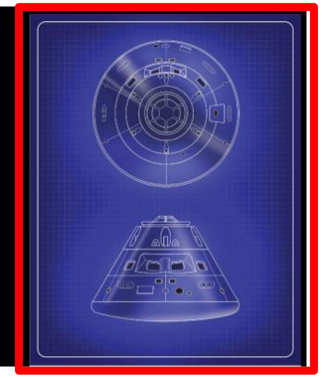
Artemis Elements



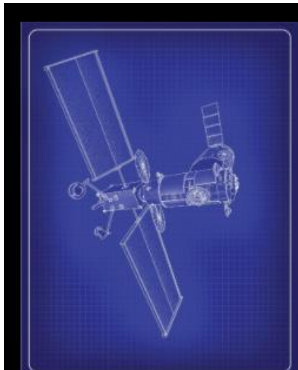
Exploration Ground Systems (EGS)



Space Launch System (SLS)

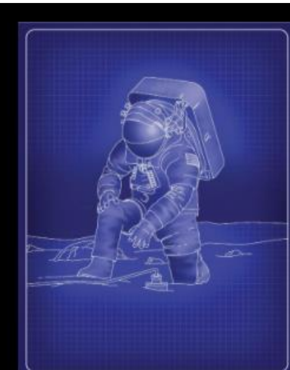


Orion (Spacecraft)



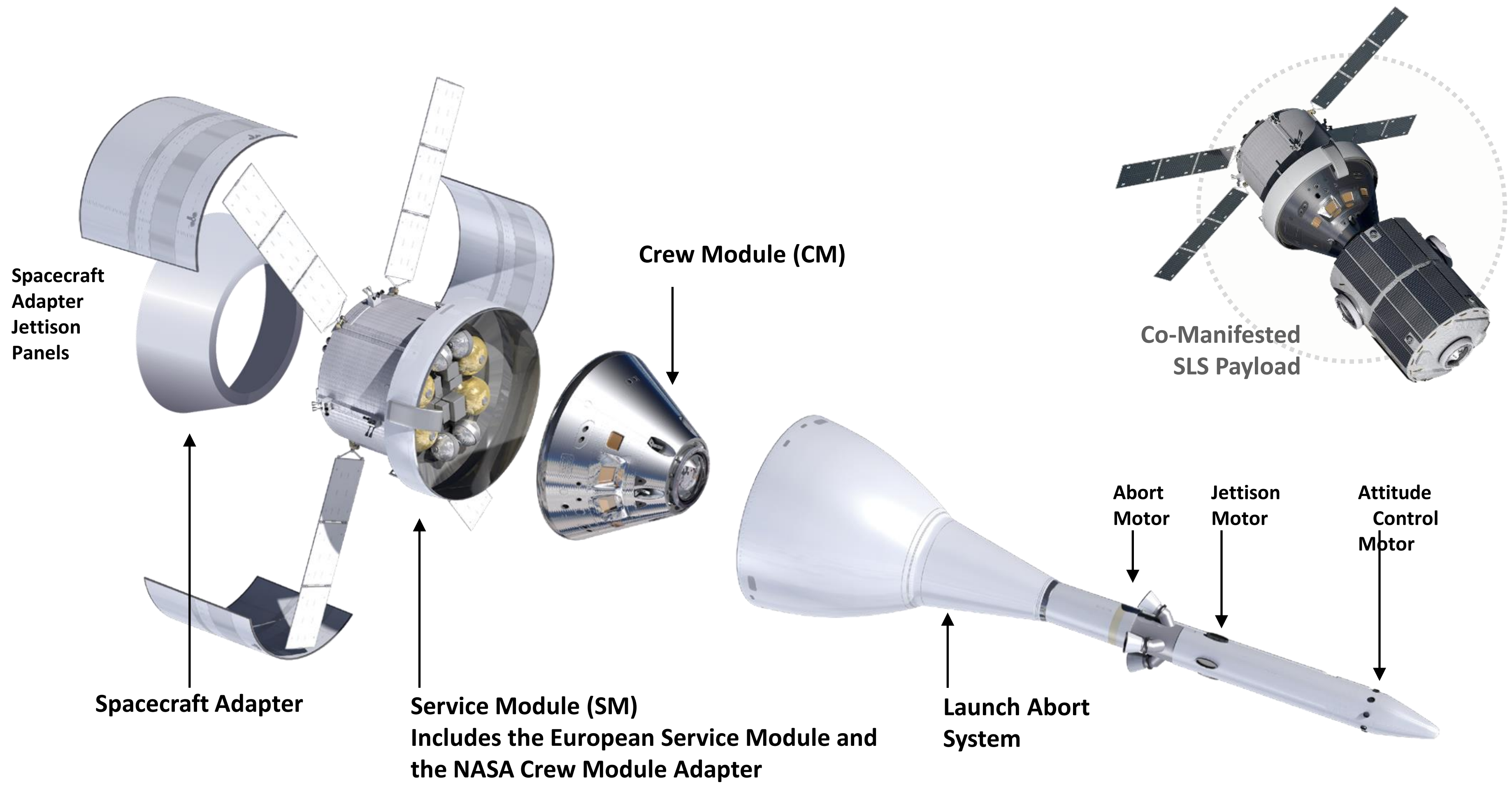
Gateway (Lunar outpost)

Lunar Lander



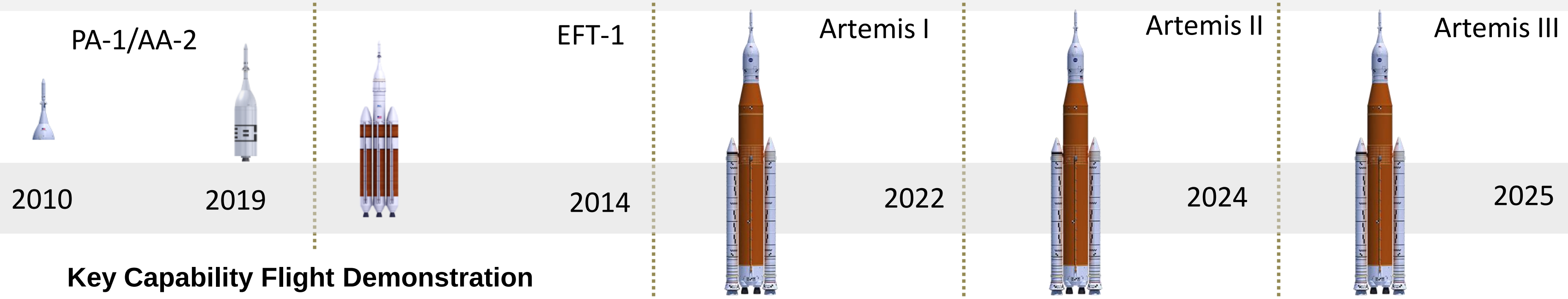
Artemis Generation Spacesuits

Orion Spacecraft Overview



NASA Prime Contractor: Lockheed-Martin
ESA Prime Contractor: Airbus

Orion Spacecraft Capabilities Maturation



Key Capability Flight Demonstration

PA-1/AA-2 (2010, 2019)

- LAS Abort Performance
- Ascent Separation Events
- Low Altitude Parachute Performance (PA-1)

EFT-1 (2014)

- LAS Abort Performance*
- Ascent Separation Events
- Heatshield/TPS Performance (9 km/s)
- Entry/Descent/Landing Performance (GNC, Parachutes)
- Orbit/Entry Separation Events
- Vehicle System Management (Avionics/Software)
- CM Core Vehicle Systems (Power, ATCS, structures, etc.)

* Not Active (Inert Abort Motor)

Artemis I (2022)

- LAS Abort Performance*
- Ascent Separation Events
- Heatshield/TPS Performance (11 km/s)
- Entry/Descent/Landing Performance (GNC, Parachutes)
- Orbit/Entry Separation Events
- Vehicle System Management (Avionics/Software)
- CM Core Vehicle Systems (Power, ATCS, structures, etc.)
- SM Ascent Abort Capability **
- Orbit/Lunar GN&C Performance
- OMS-E/Aux Prop Performance
- SM Core Vehicle Systems (Power, ATCS, Structures, etc.)

* Not Active (Inert Abort Motor)
** Not Demonstrated

Artemis II (2024)

- LAS Abort Performance
- Ascent Separation Events
- Heatshield/TPS Performance (11 km/s)
- Entry/Descent/Landing Performance (GNC, Parachutes)
- Orbit/Entry Separation Events
- Vehicle System Management (Avionics/Software)
- CM Core Vehicle Systems (Power, ATCS, structures, etc.)
- SM Ascent Abort Capability **
- Orbit/Lunar GN&C Performance
- OMS-E/Aux Prop Performance
- SM Core Vehicle Systems (Power, ATCS, Structures, etc.)
- ECLSS
- Crew Systems (Displays, Hand Ccontrollers, Waste Management, etc.)

** Not Demonstrated

Artemis III (2025)

- LAS Abort Performance
- Ascent Separation Events
- Heatshield/TPS Performance (11 km/s)
- Entry/Descent/Landing Performance (GNC, Parachutes)
- Orbit/Entry Separation Events
- Vehicle System Management (Avionics/Software)
- CM Core Vehicle Systems (Power, ATCS, structures, etc.)
- SM Ascent Abort Capability **
- Orbit/Lunar GN&C Performance
- OMS-E/Aux Prop Performance
- SM Core Vehicle Systems (Power, ATCS, Structures, etc.)
- ECLSS
- Crew Systems (Displays, Hand Controllers, Waste Management, etc.)
- Rendezvous, Prox Ops and Docking (RPOD)

** Not Demonstrated

LEGEND:

- ■ First time flight
- ■ Previously flown

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

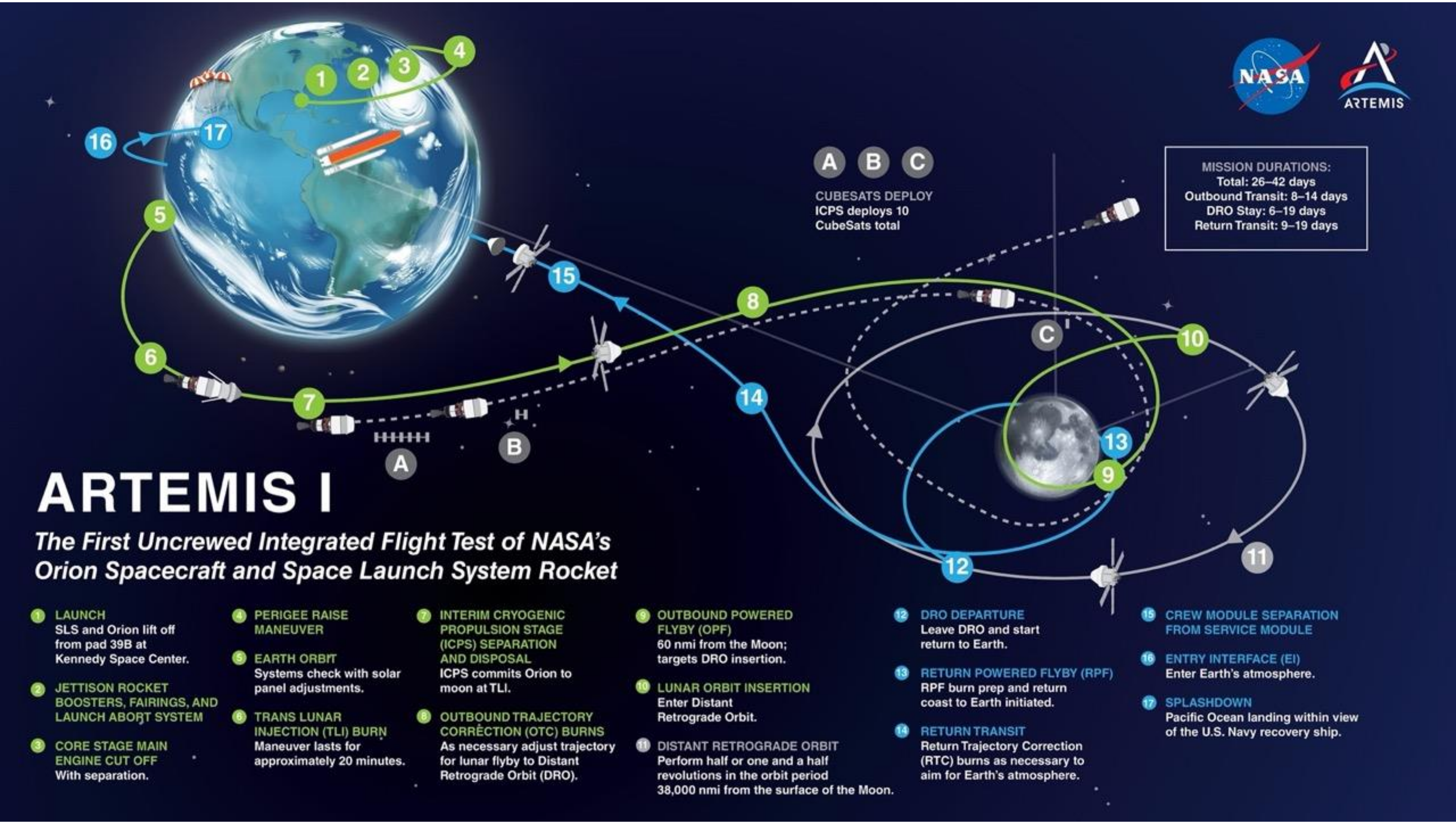
Artemis I	53,000 lbs.
Artemis II	58,000 lbs.

Artemis 1 Mission Overview

(for 8/29 launch)

- **Flight Day 1 (8/29, 8:33 a.m.) - Liftoff through trans-lunar injection**
- **Flight Day 2-5 - Outbound transit**
  - Flight Day 5 (9/3): Outbound Flyby (burn 9:11 p.m.), Lunar Closest Approach (~60 miles)
- **Flight day 6-9 - Transit to Distant Retrograde Orbit (DRO) around the Moon**
  - Flight Day 8 (9/5): Labor Day
- **Flight Day 10-23 - In DRO**
  - Flight Day 10 (9/7): DRO Insertion (burn 8:54 a.m.)
  - Flight Day 11 (9/8): Orion passes Apollo 13 Record
  - Flight Day 15 (9/12): JFK speech 60th anniversary
  - IAC (9/18-22)
- **Flight Day 24-34 - Exit DRO**
  - Flight Day 24 (9/21): DRO Departure (burn 2:52 a.m.)
  - Flight Day 26 (9/23): Max distance from Earth
- **Flight Day 35-42 - Return transit**
  - Flight Day 35 (10/3): Return Flyby (burn 12:06 a.m.), Second Closest Approach (~500 miles)
- **Flight Day 43 (10/10)- Entry and splashdown (11:53 a.m.)**
  - Columbus day

Artemis 1 Mission Overview



Artemis I Payloads

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

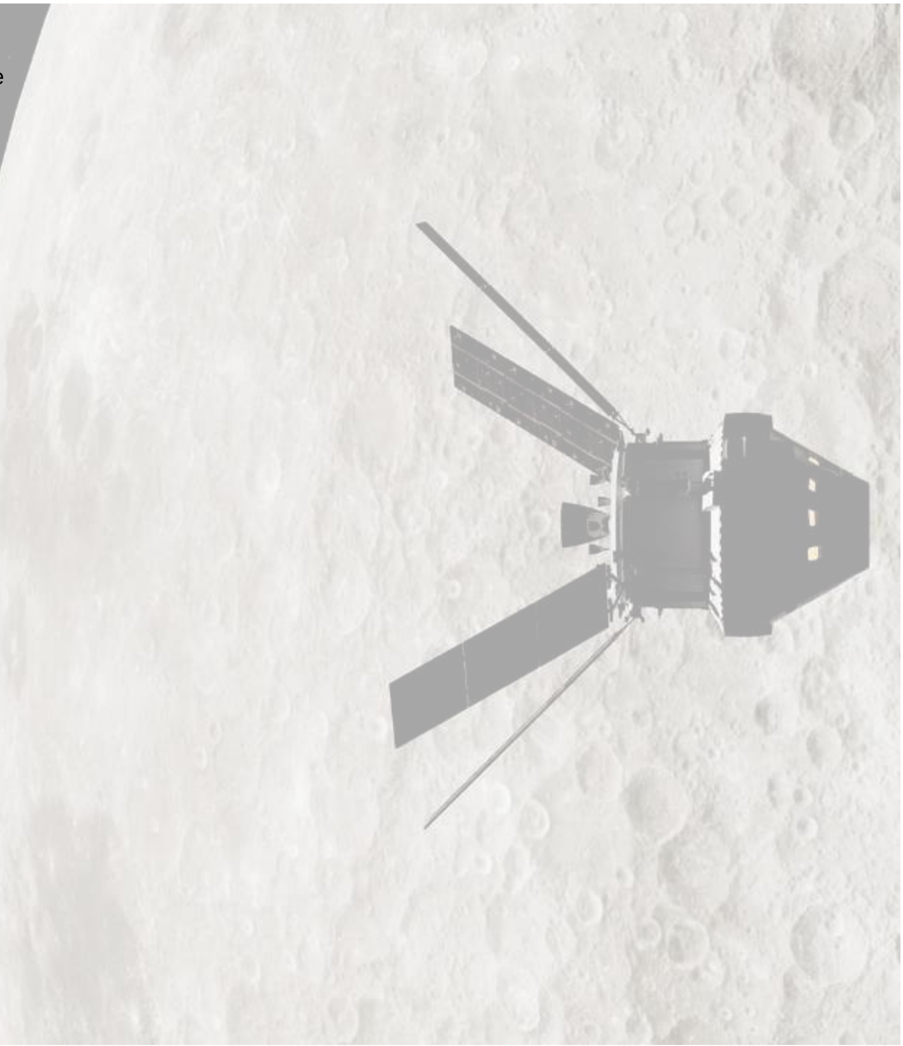
Radiation shielding Personal Protection Equipment (radiation vest) for astronauts.

Crew Interface Technology Payload (CITP)

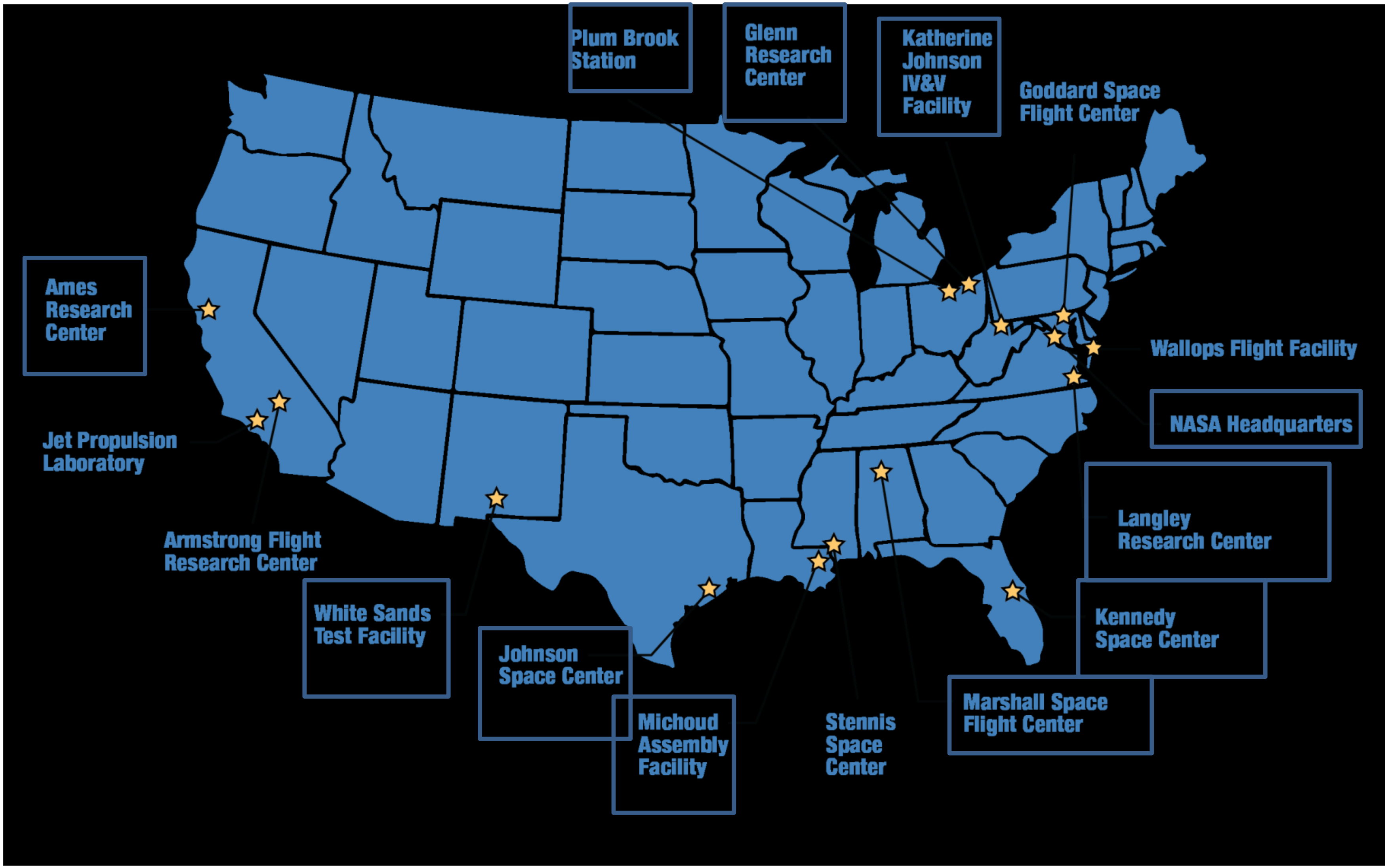
Creates an interactive experience between Orion and the public during the mission

Bio-Experiment-1

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

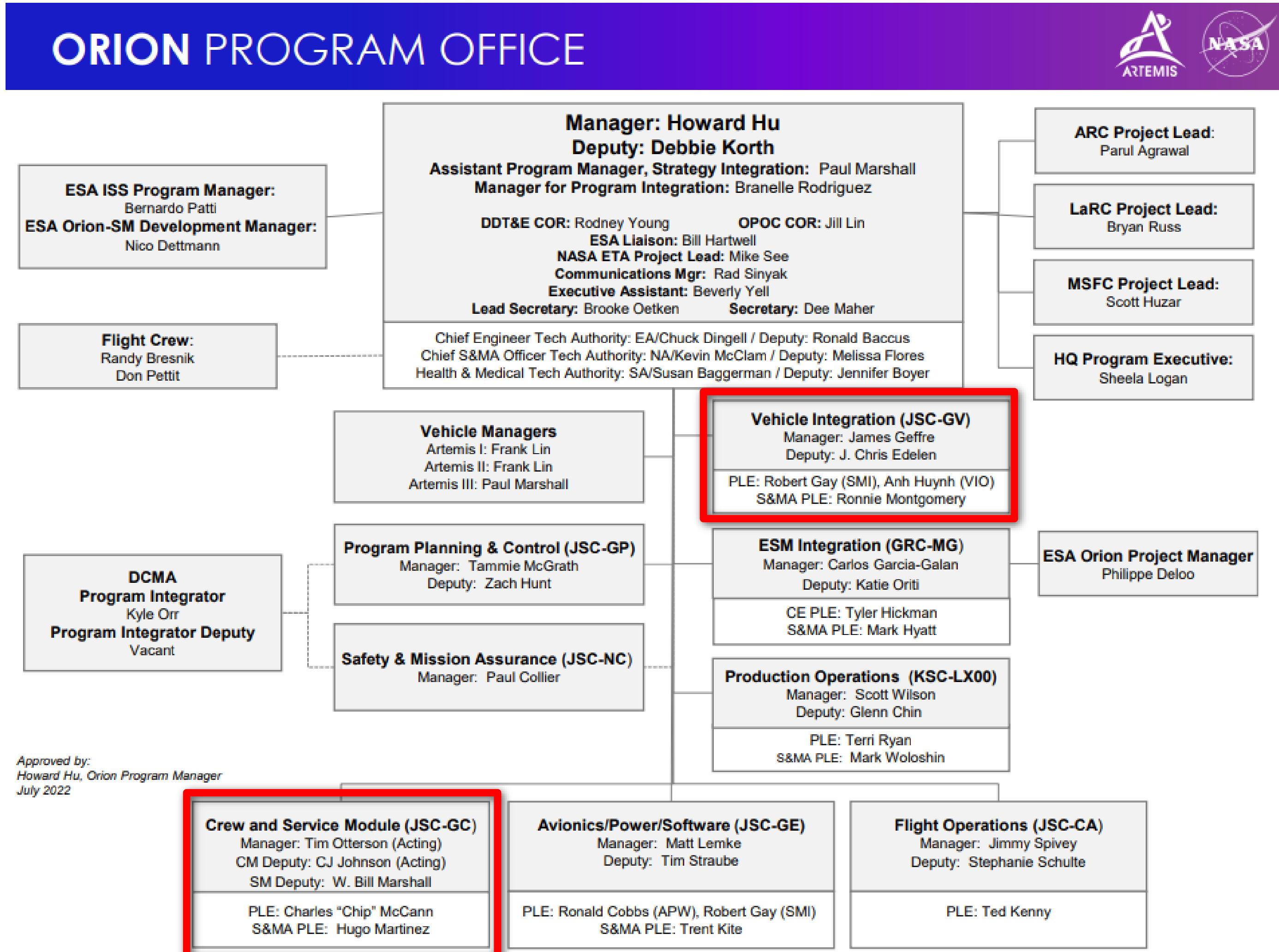


Key Artemis Contributions by NASA Center



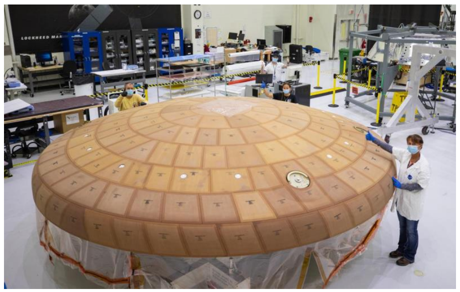
Orion NASA Organization

- Multi NASA Center Program
- Strong, independent Engineering, Safety and Health & Medical Technical Authorities
- Orion to ESD/Gateway/HLS integration led by VIO and supported by Product Teams
- NASA/ESA integration led by EIO and supported by Product Teams
- Significant insight into Prime Contractor and ESA partner activities
- Evolution to “lean” production org in work



ARC Technical Support Areas

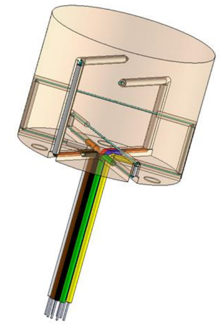
Crew Service Module (CSM) : TS, AA and RE



Heatshield testing, system analysis, recovery and post flight support

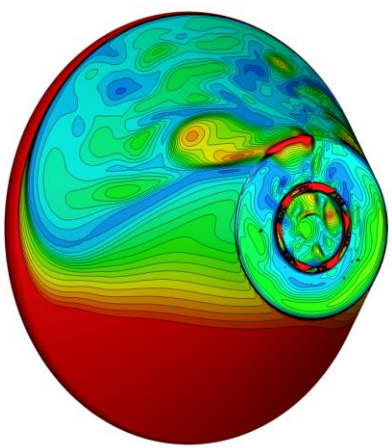
Backshell testing, analysis recovery and post flight support

Arcjet testing

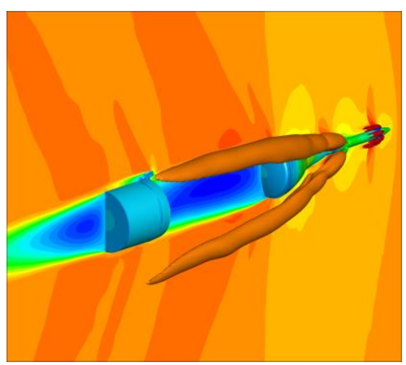


TPS Development Flight Instrumentation (DFI)

Vehicle Integration Office (VIO): TS, AA, TN and AO

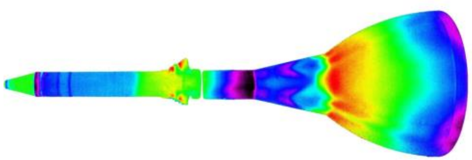


Aerothermal environment and Aerothermal database generation



Vehicle Aerodynamics, wind tunnel test support and aero database

wind tunnel testing



Launch abort environments, acoustics and vibrations

ARC Orion Team Leads

Jeremy Vander Kam (TPS)

Ryan McDanial (Aerosciences)

Joseph Garcia – Aerosciences

Ed Martinez (TPS - DFI)

Jose Santos (TPS-DFI)

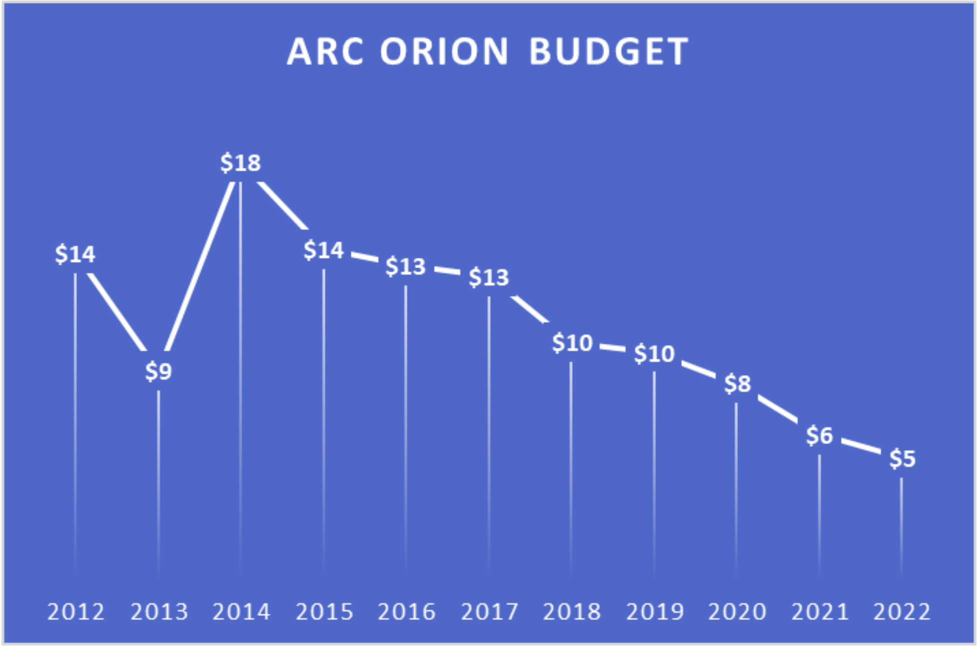
Jay Panda (Loads & Dynamics)

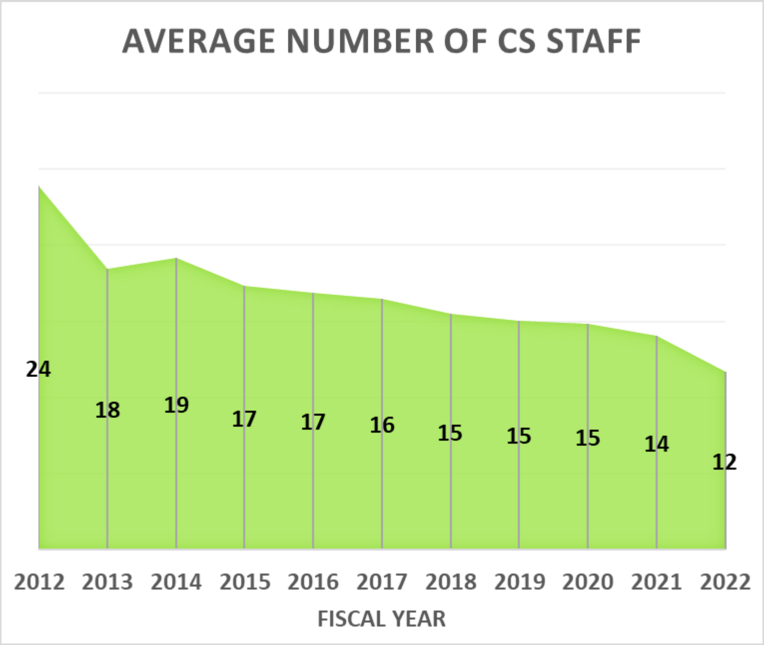
Cetin Kiris (Loads & Dynamics)

Amanda Rockwell (Resource Analyst)

Sarah D’Souza – TPS
Joseph Olejniczak – Aerosciences
James Ross – Wind Tunnel tests
Geoff Cushman – LEAF-Lite
Alberto Makino - Structures

Orion @ ARC – Financial Data

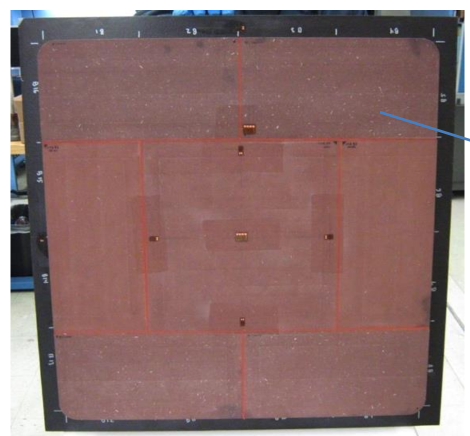


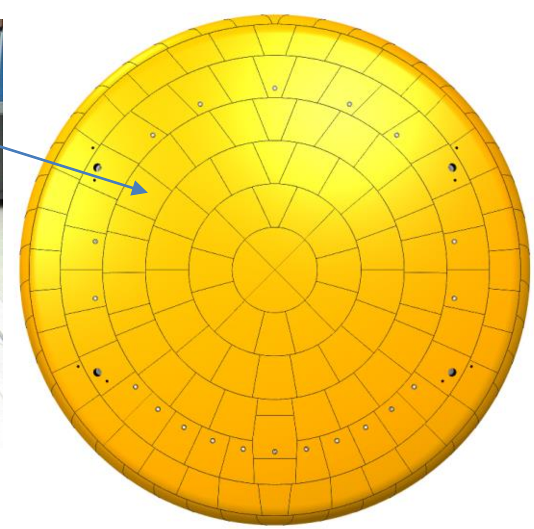


Orion TPS - Heat Shield

- 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





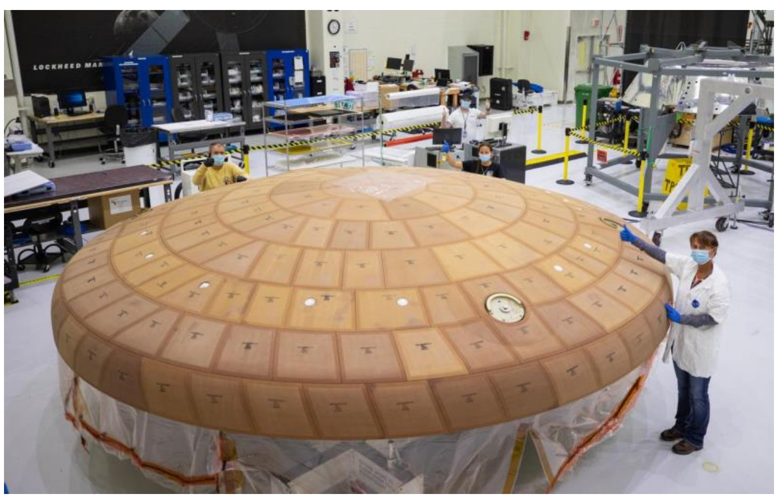
POC: Jeremy Vander kam

Reference : https://www.nas.nasa.gov/pubs/ams/2022/04-07-22.html

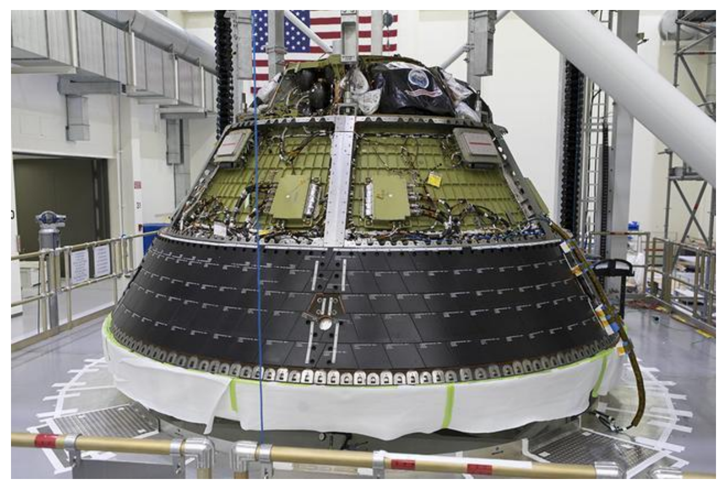
15

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.



AVCOAT block bonding on the Artemis II heat shield

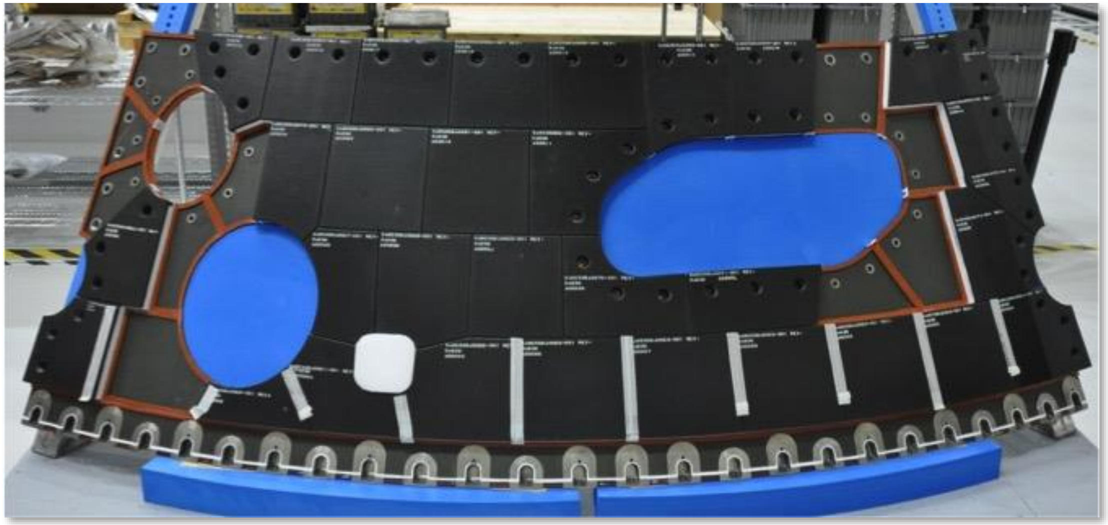


Heat shield back shell panels are prefitted on the Orion Spacecraft

Orion TPS - Backshell & FBC

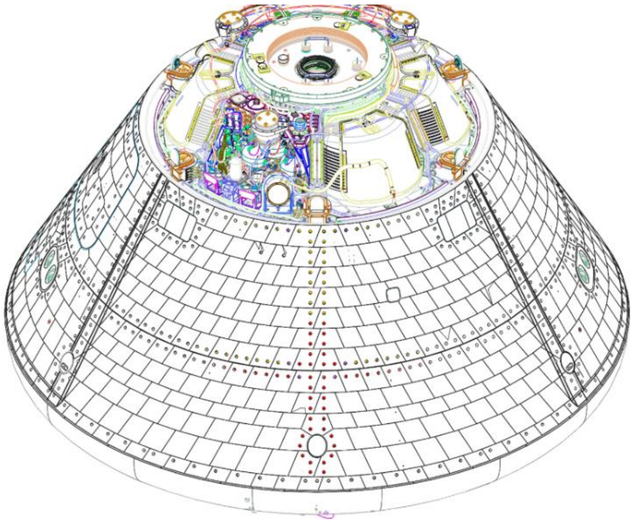
- Alumina-Enhanced Thermal Barrier (AETB-8 tiles) with RCG over TUFI coating (Shuttle heritage)
- Removable panels with threaded tile plugs providing fastener access
- Flexible Reusable Surface Insulation (FRSI) used on upper apex surface
- Penetrations utilized thermal barriers, carbon phenolic, RTV and FRSI

Forward Bay Cover, with Side Panel Removed



Panel A, Tiles Partially Installed

POC: Jeremy Vander kam, Marc Rezin

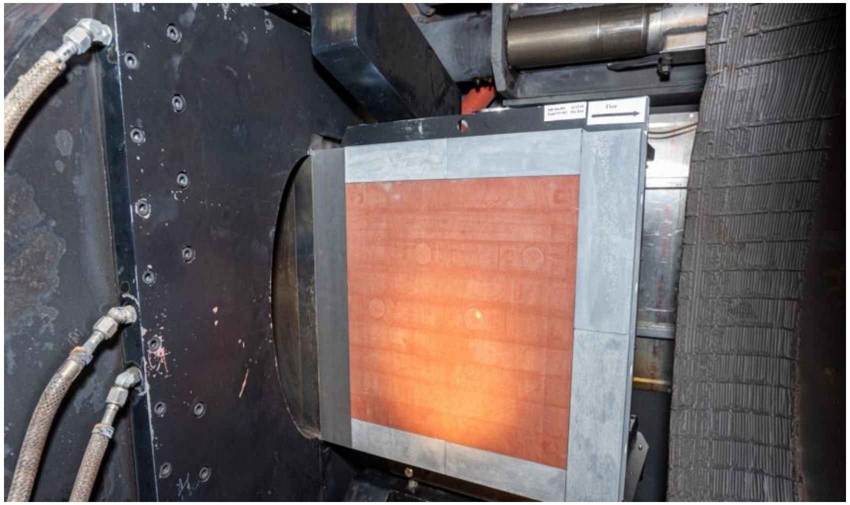


Back Shell TPS, Wind Side
(Forward Bay Cover Not Shown)

Orion TPS – Arcjet Tests

Orion TPS team designs, plans and executes the heatshield and backshell material and system level tests to provide a preview of performance in entry like conditions and generate data for thermal response and aerothermal databases. Test campaigns are conducted in

- IHF/LEAF
- AHF
- PTF

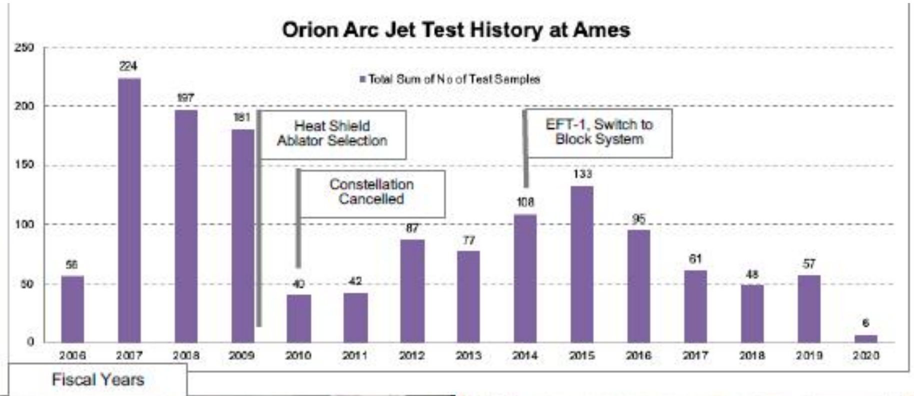


Orion panel test article mounted in IHF/LEAF for combined convective and radiative test

Orion heatshield material exposed to arcjet plasma

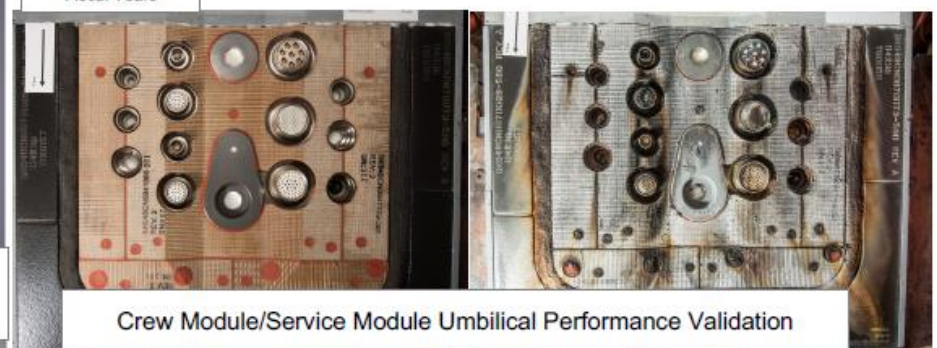
Orion TPS - Arc Jet Test Summary

- **Since 2006, Orion has completed > 1,420 arc jet tests at NASA Ames Research Center**
  - Does not include arc jet tests at NASA JSC and the Arnold Engineering Development Center (AEDC) in Tennessee - another ~200 tests




Heat Shield Avcoat Block/Seam Array in Combined Convective/Radiant Heating


Heat Shield Seam Evaluations in High Heating Environments


Crew Module/Service Module Umbilical Performance Validation

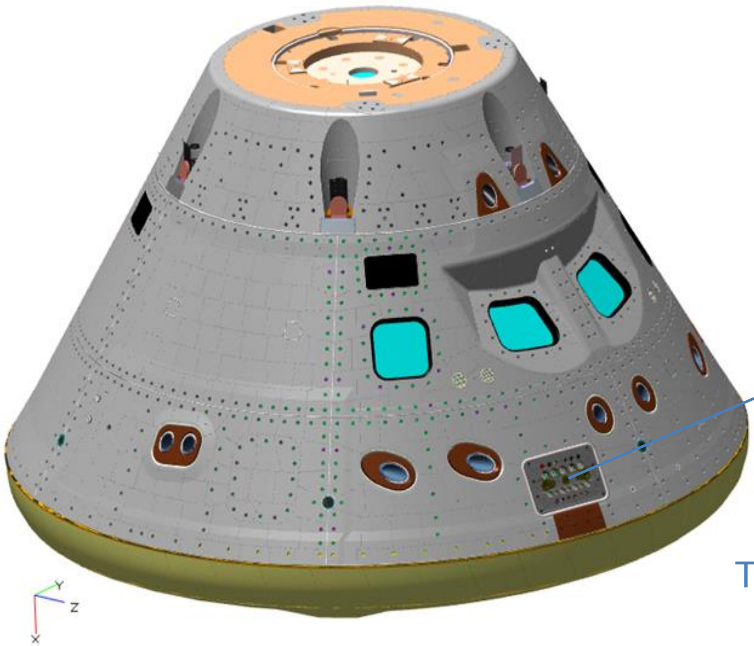

Crew Module Recovery Mechanism Hot Functional Testing

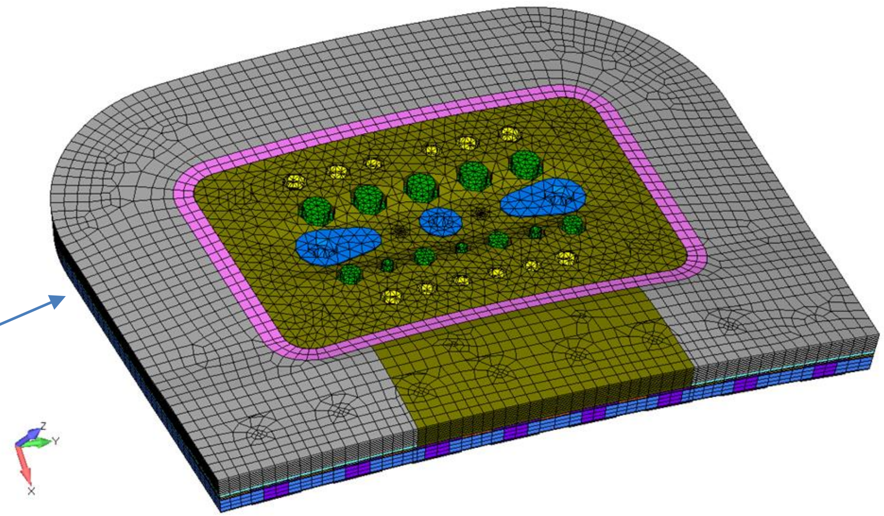
POC: Jeremy Vander kam

Reference : https://www.nas.nasa.gov/pubs/ams/2022/04-07-22.html

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.



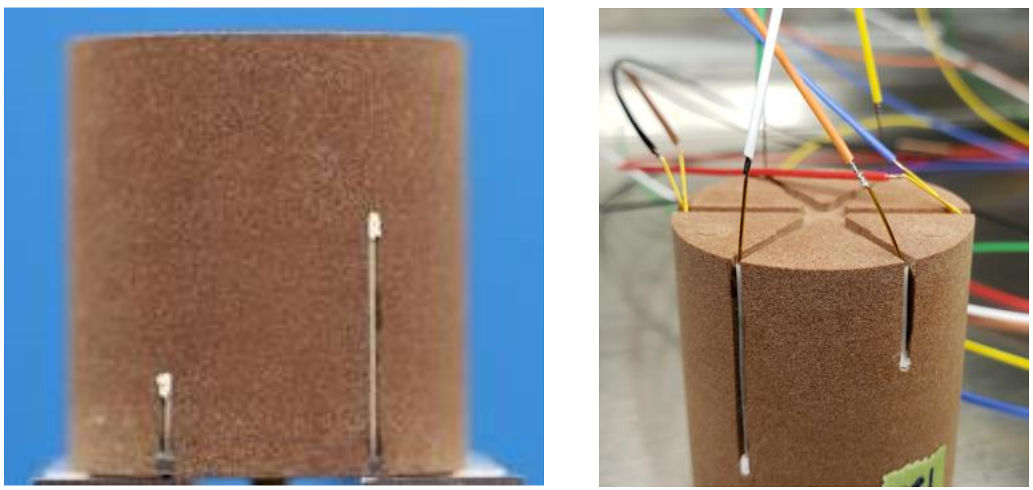


Thermal Analysis and verification of umbilical panel

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

Orion TPS DFI (Development Flight Instrumentation)

- Objective - deliver Artemis 1, 2, 3 + instrumentation hardware (heatshield and backshell) for measuring 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 has numerous embedded sensors that include – Thermal plugs, Flush Air Data System, Kulites, Radiometer, spectrometer, Optical recession sensors,

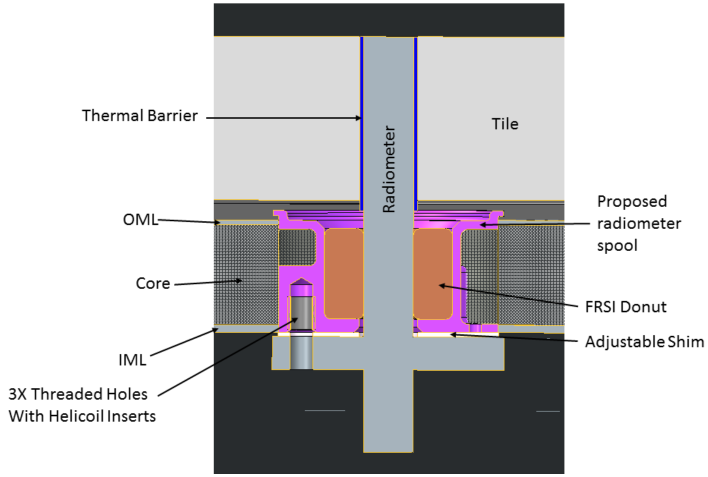


Artemis 1& 2 Thermal Plugs with embedded Thermocouples

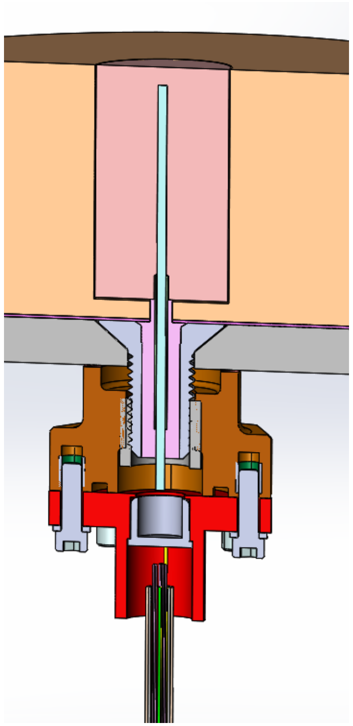
Artemis-1 Radiometer sub-assembly

POCs: Ed Martinez, Jose Santos

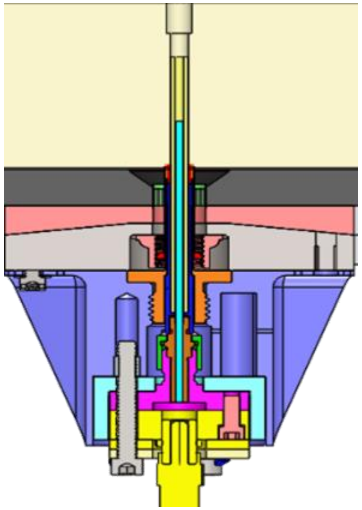
DFI Sensors



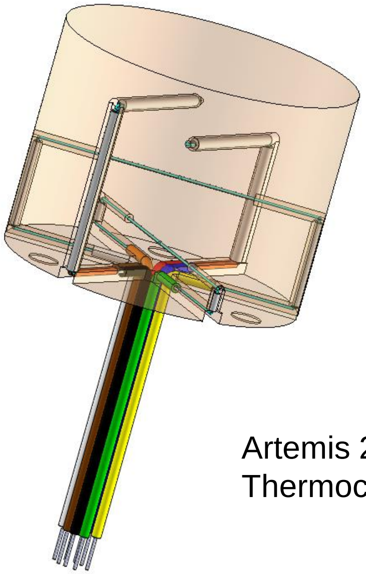
Flush Mounted Radiometer through Backshell Tile (Illustration by LMSSC)



Artemis 2 Heat Shield Optical Recession Sensor (ORS)



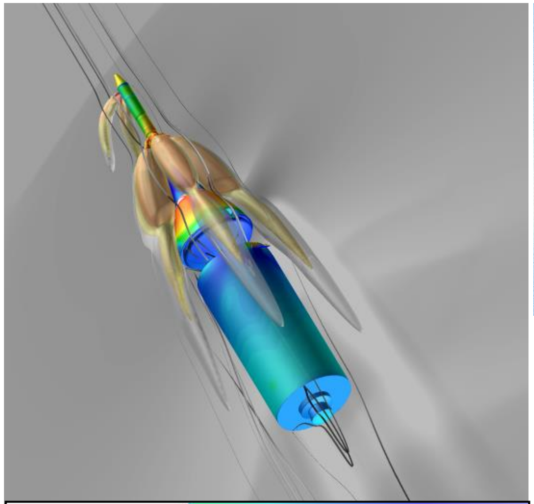
Artemis 2 Heat Shield Spectrometer Optics

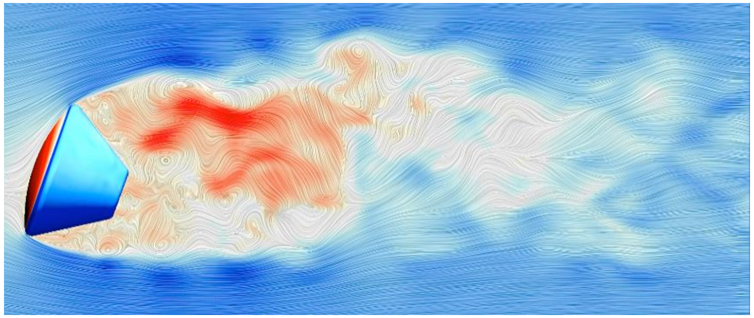


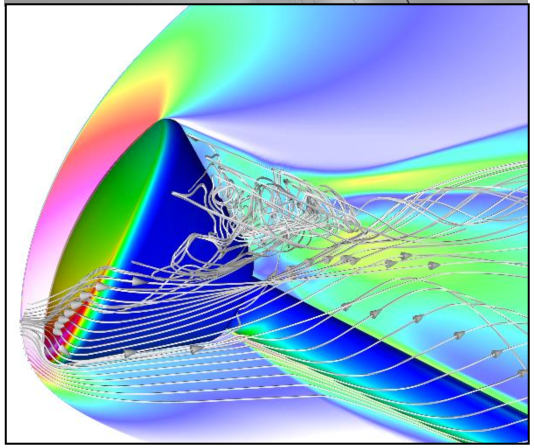
Artemis 2 Heat Shield Thermocouple (TC) plug

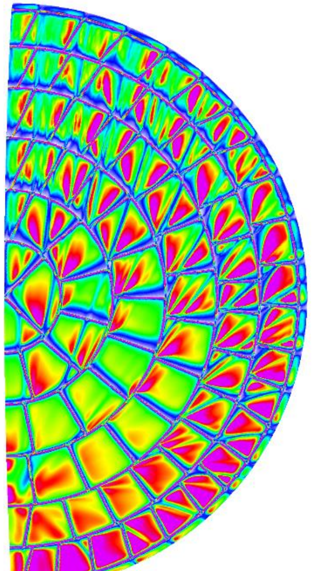
Orion Aerosciences

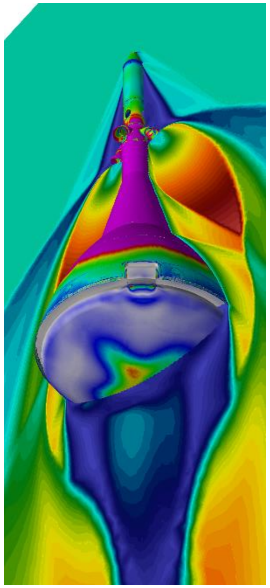
- **CFD is used to develop environments for Aerodynamics and Aerothermodynamics for all phases of flight**
- **CFD tools are validated utilizing ground and flight test data before applying it in design analyses**
- **Key challenges for CFD in Orion Aerosciences**
  - Aero: Complex geometries, turbulence,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

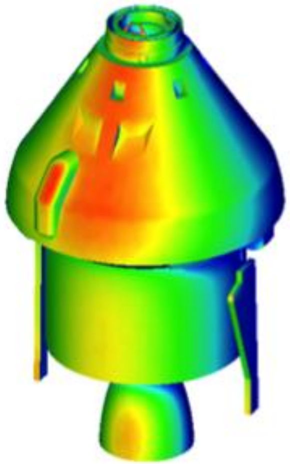


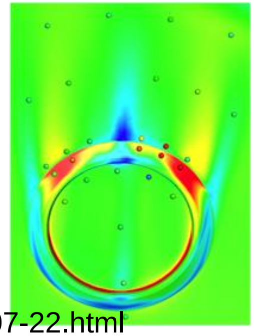


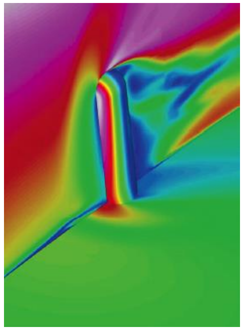








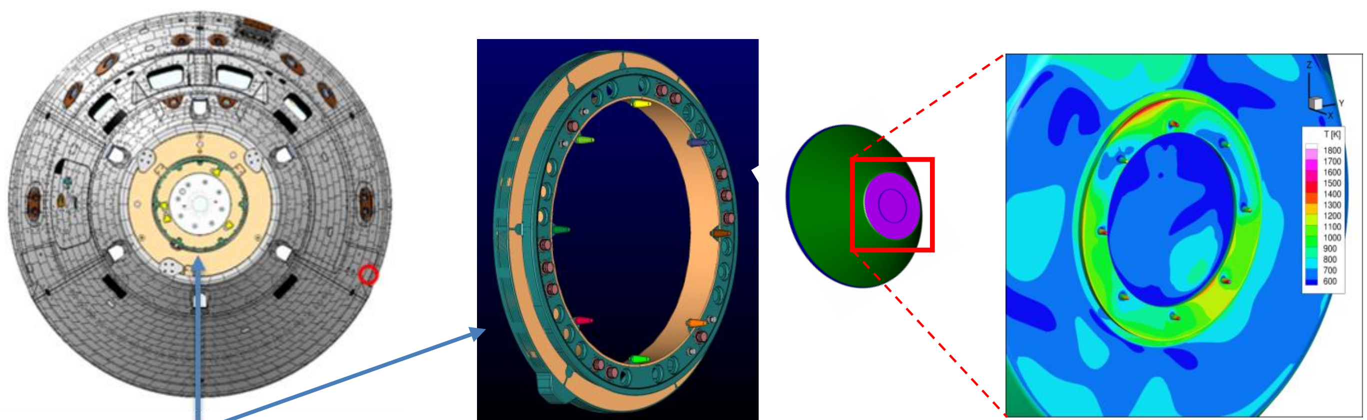




Reference : https://www.nas.nasa.gov/pubs/ams/2022/04-07-22.html
Orion Aerosciences: Aerothermal Database Development, Ryan McDaniel

Aerosciences - Aerothermodynamics

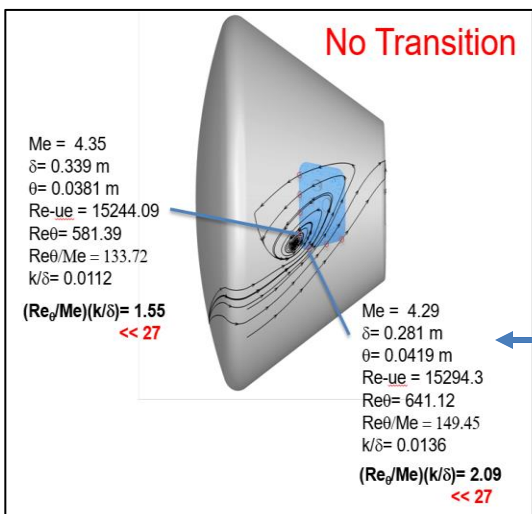
ARC aerothermal team supports aerothermal database generation, launch and flight environment predictions, data verifications, ground test design and verifications.



docking ring

Figure 1: Simulation of temperature contours on the docking ring

Analysis of docking ring and protruding rods



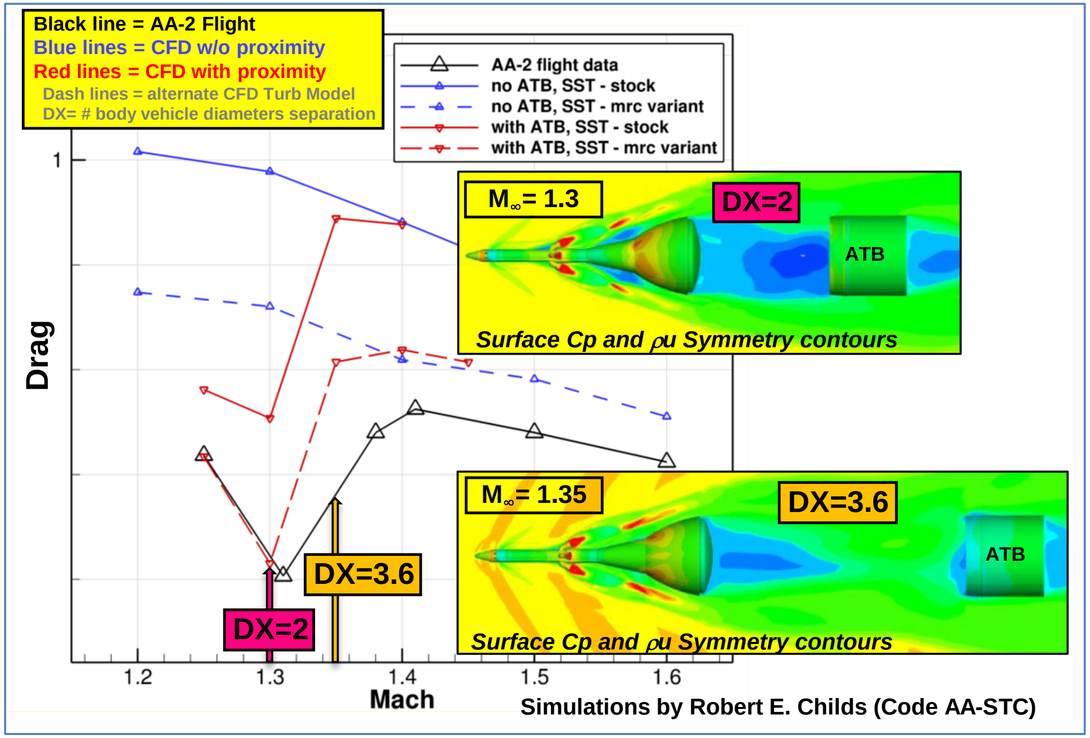
Side hatch Protrusion Analysis for potential boundary layer transition

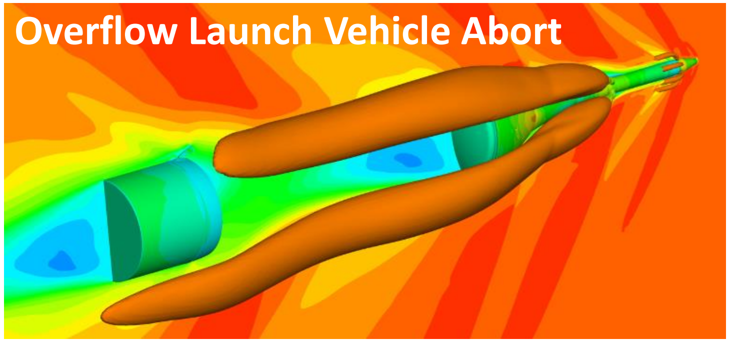
POC – Ryan McDaniel

Aerosciences - Aerodynamics

ARC aerodynamics team provide technical support in the development of CFD best practices for aerodynamic analysis and delivery of CFD simulations for NASA's Orion Aerodynamic databases for all Artemis missions

- Support of Orion's LAV Aerodynamics Database V0.96
- Root Cause Investigation of AA-2 [07/02/2019 test] LAV Drag Miss
- Artemis-1 Best Estimated Trajectory (BET) reconstruction support





POC – Joseph Garcia

Orion Launch abort System Support

- Collaboration between Orion Loads and Dynamics team at Johnson Space Center and Launch, Ascent, and Vehicle Aerodynamics (LAVA) team at Ames
- Goal: Incorporate Computational Fluid Dynamics (CFD) predictions to the wind tunnel, ground, and flight test data used to characterize the vibro-acoustic environment of the Orion Launch Abort System (LAS) – to ensure it doesn't shake itself apart
- Motivation:
  - To help reduce uncertainty: WT/ground/flight tests are few in number, have limited sensors, are costly, and don't cover all possible abort trajectories
  - To help better understand how altitude, Mach number, and acceleration, affect the strength and distribution of vibrations on LAS

POCs: Cetin Kiris , Francois Cadieux

Launch Abort System

Ensuring Astronaut Safety

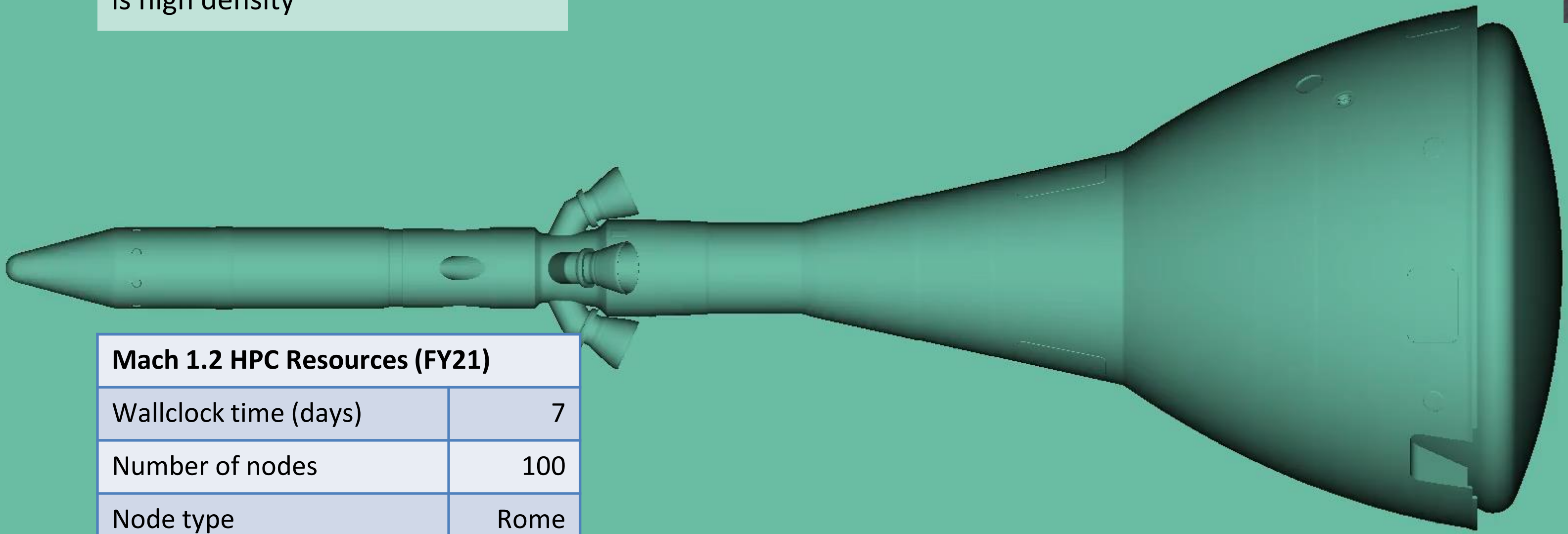
NASA is developing technologies that will enable humans to explore new destinations in the solar system. America will use the Orion spacecraft, launched atop the Space Launch System rocket, to send a new generation of astronauts beyond low-Earth orbit to places like an asteroid and eventually Mars. In 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

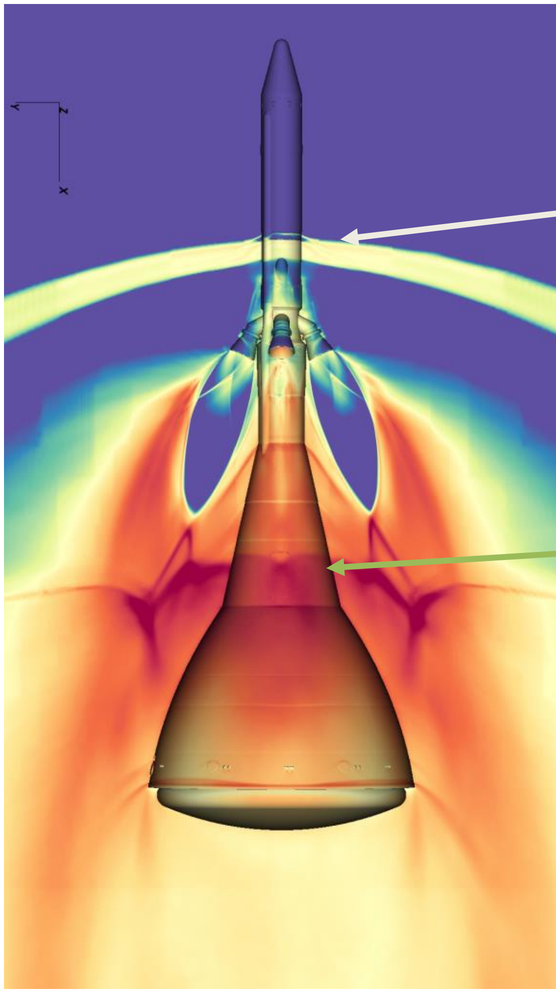
Video from AA-2 Mach 1.615 simulation: logarithm of density on the cut plane and vehicle surface, where red is low and blue is high density



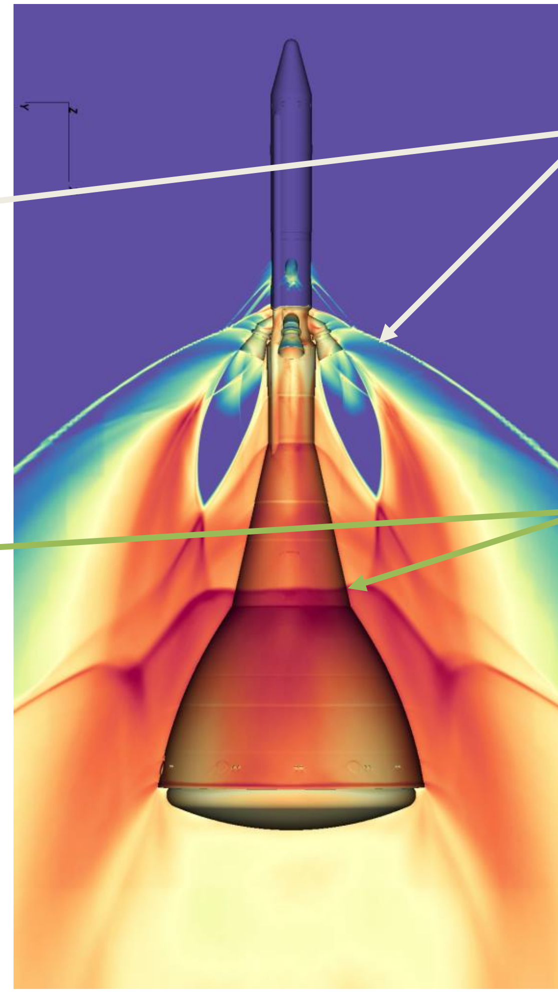
Mach 1.2 HPC Resources (FY21)	
Wallclock time (days)	7
Number of nodes	100
Node type	Rome
Total number of cores	12,800
Time simulated (seconds)	0.58
Volume data (TB)	100

Effect of Mach Number on OASPL

AA-2 CFD M_∞ =1.17



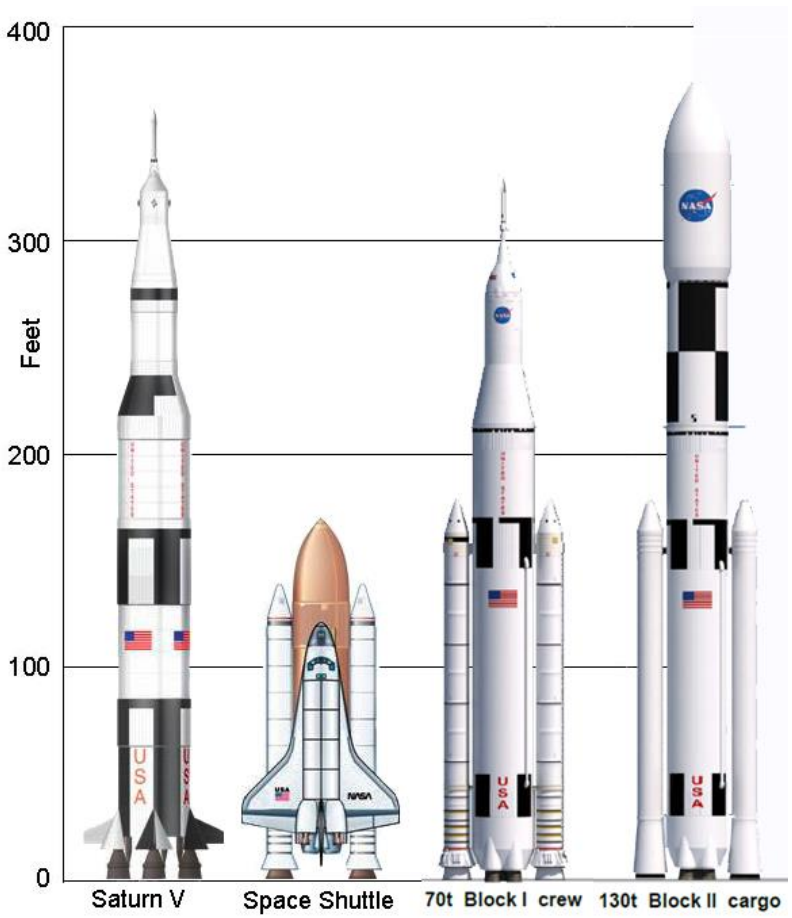
AA-2 CFD M_∞ =1.62

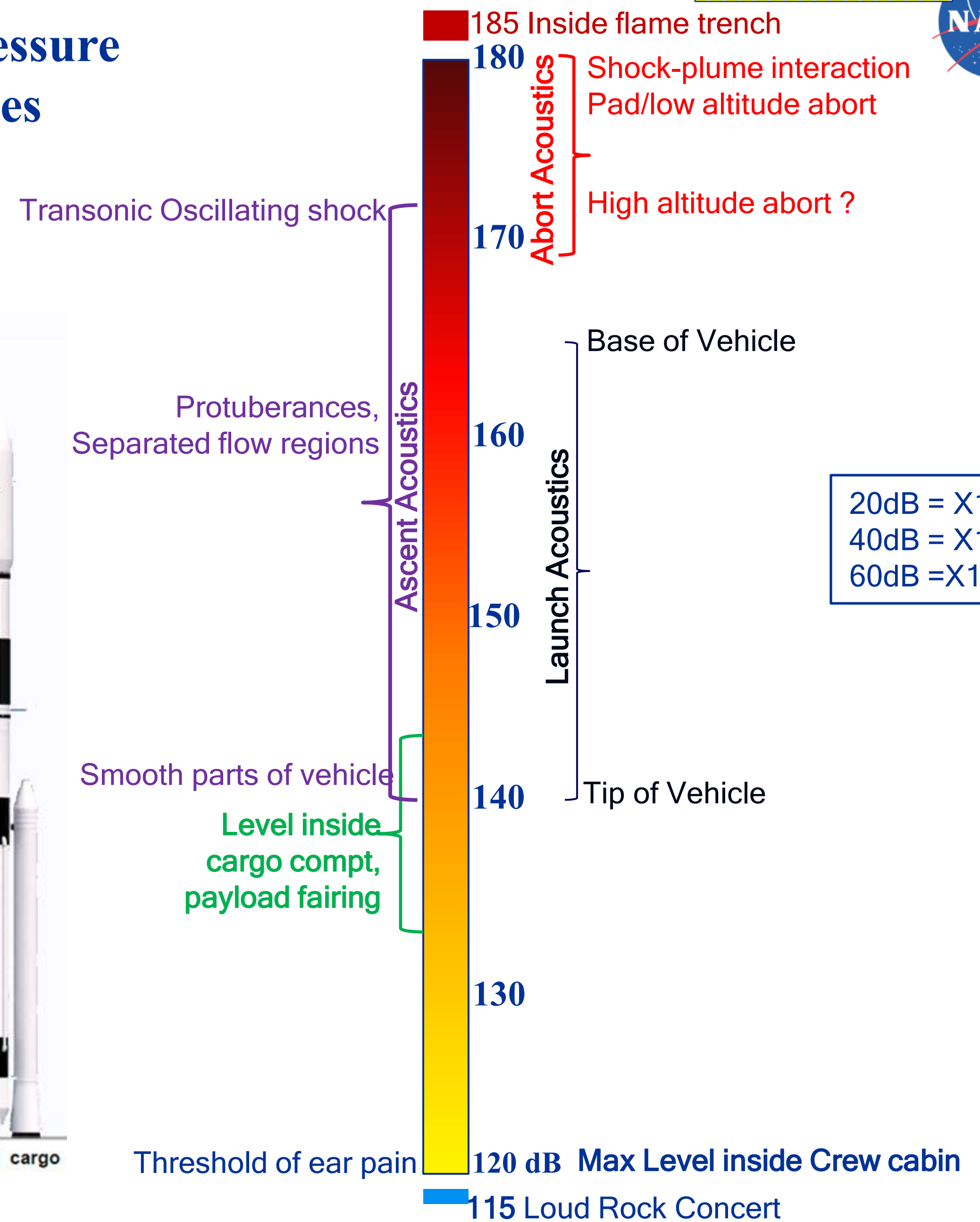


Abort motor nozzle and plume bow shock

Plume shock interaction due to vehicle change in cross-sectional area goes right through zone H for Mach 1.62

Typical levels (dB) of surface pressure fluctuations on launch vehicles





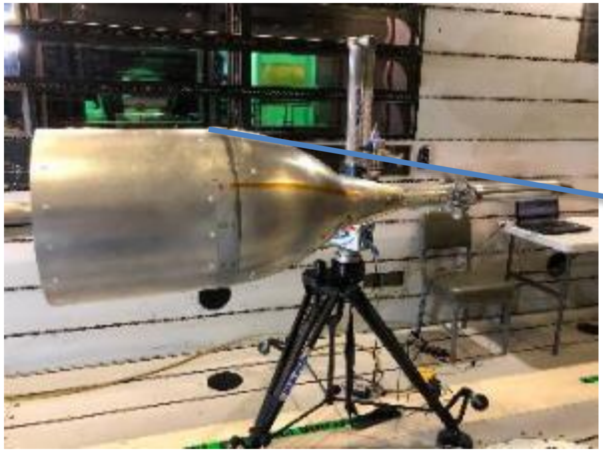
20dB = X10
40dB = X100
60dB =X1000

Wind tunnel Tests for Aeroacoustics

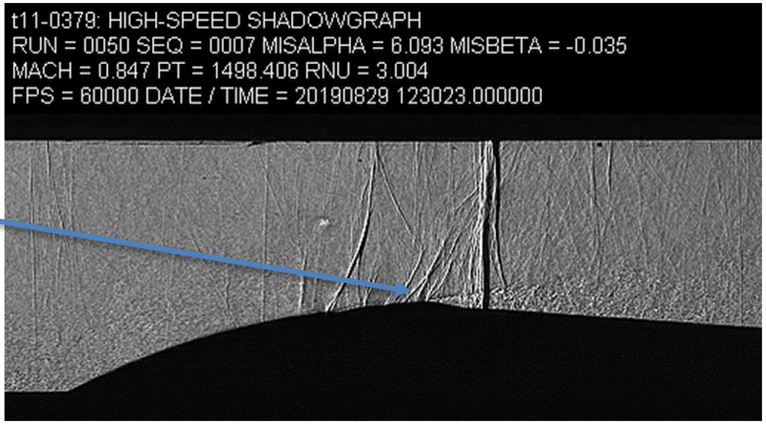
Several windtunnel tests have been conducted at ARC to understand the launch environments.

The aeroacoustics test to study the surface pressure fluctuations at CM_SM umbilical was successfully conducted at 11-ft Unitary wind tunnel in 2019 .

The results show significant reduction in the overall acoustic environment and efforts continue to further reduce the environment based on this test data.



7.5% Orion scaled model exposed to Mach0.8-1.4 with AoA and beta sweep



flow over the umbilical cover showing complex shock-wave patterns, and interactions with separated flow and the upcoming wake

POCs : Jay Panda, Jim Ross

Summary

ARC continues to be a key contributor for Orion program in support of Artemis Mission in several areas that include heatshield development, testing and recovery, flight sensors development, aero sciences, launch abort environments and wind tunnel tests.

QUESTIONS?

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