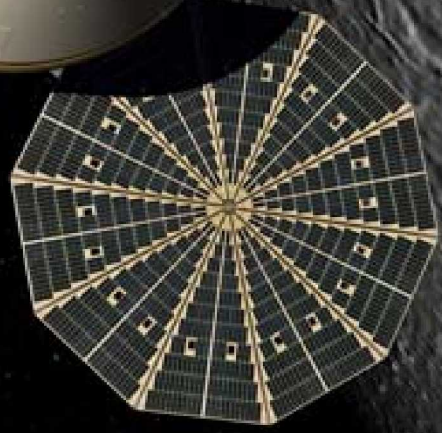




TEAWS 2009 Orion Passive Thermal Control Overview



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Houston, TX 77058**

12-Aug-2009



Topics



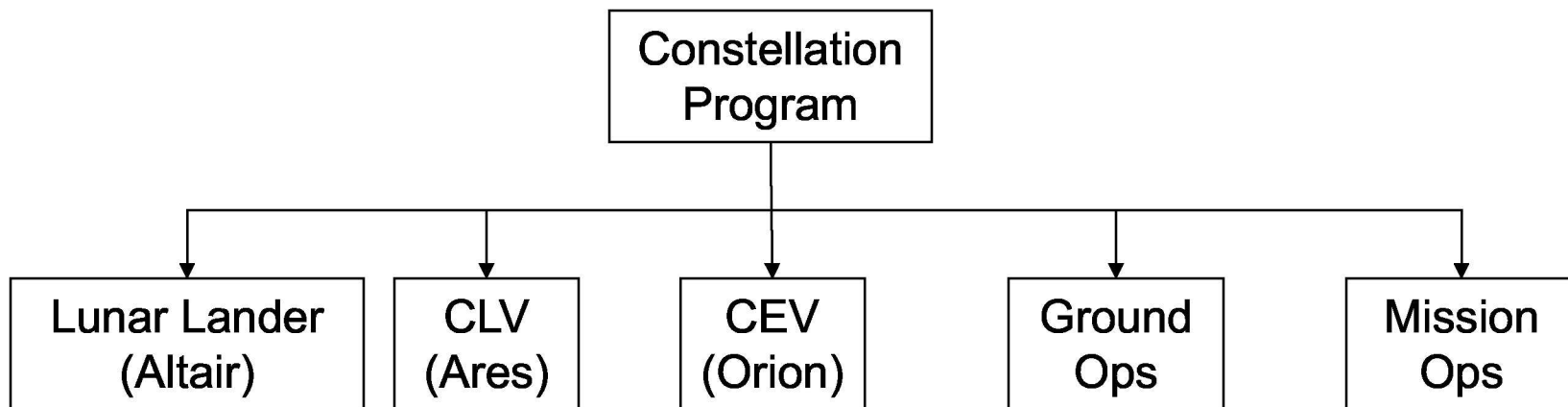
- Orion in CxP Hierarchy
- General Orion Description/Orientation
 - Module Descriptions and Images
- Orion PTCS Overview
 - Requirements/Interfaces
 - Design Reference Missions
 - Natural Environments
 - Thermal Models
 - Challenges/Issues
 - Testing



Orion in CxP Hierarchy



- Orion is the main crewed vehicle in the Constellation program.
 - Designed to carry 4 crew to/from ISS or 4 crew to/from the Moon.
- Billed as the Shuttle “replacement”
- First Flight in 2014
 - Orion 1 will be unmanned test flight.
- Will be launched on top of an Ares I vehicle.





General Orion

Description/Orientation

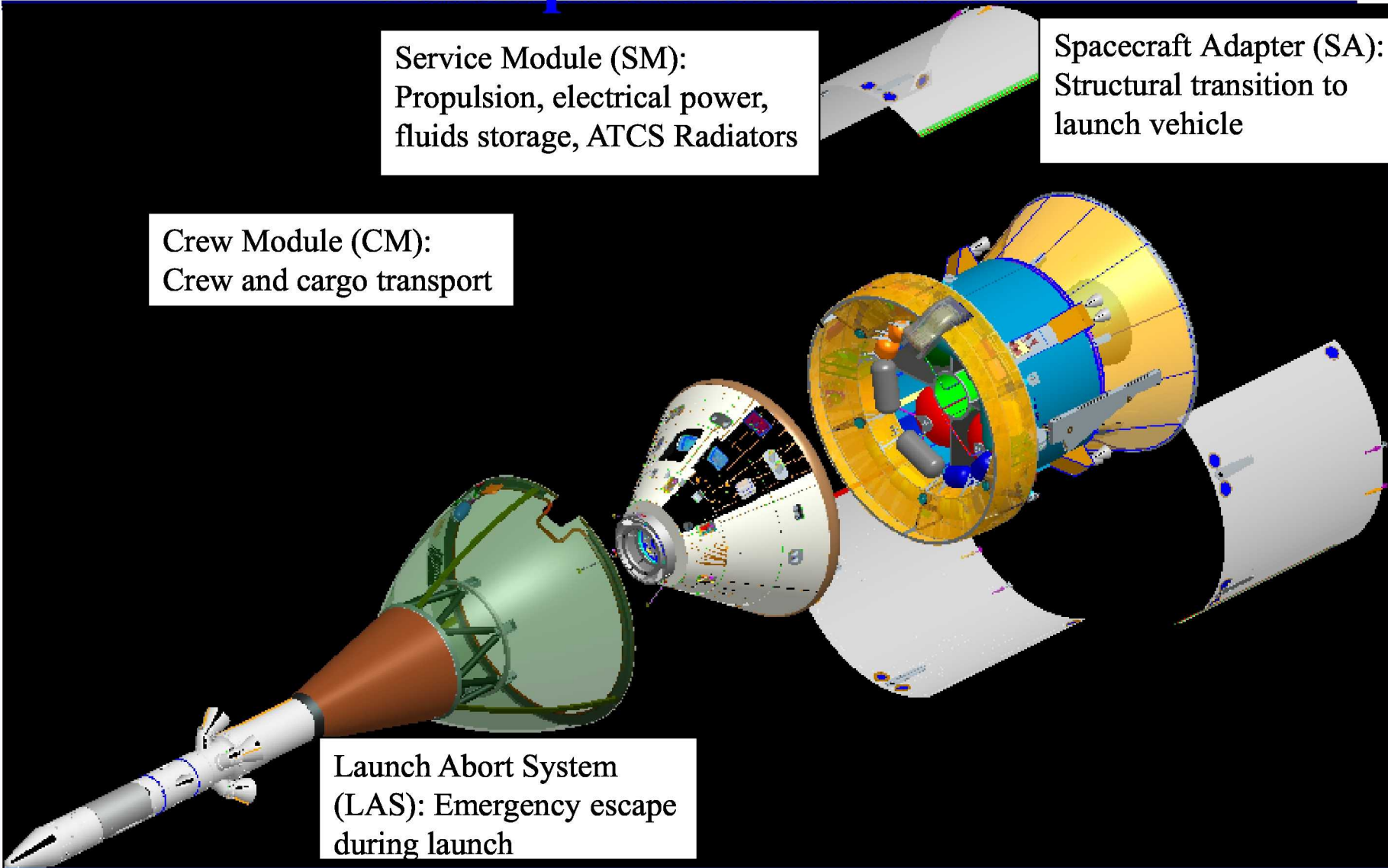


Service Module (SM):
Propulsion, electrical power,
fluids storage, ATCS Radiators

Spacecraft Adapter (SA):
Structural transition to
launch vehicle

Crew Module (CM):
Crew and cargo transport

Launch Abort System
(LAS): Emergency escape
during launch

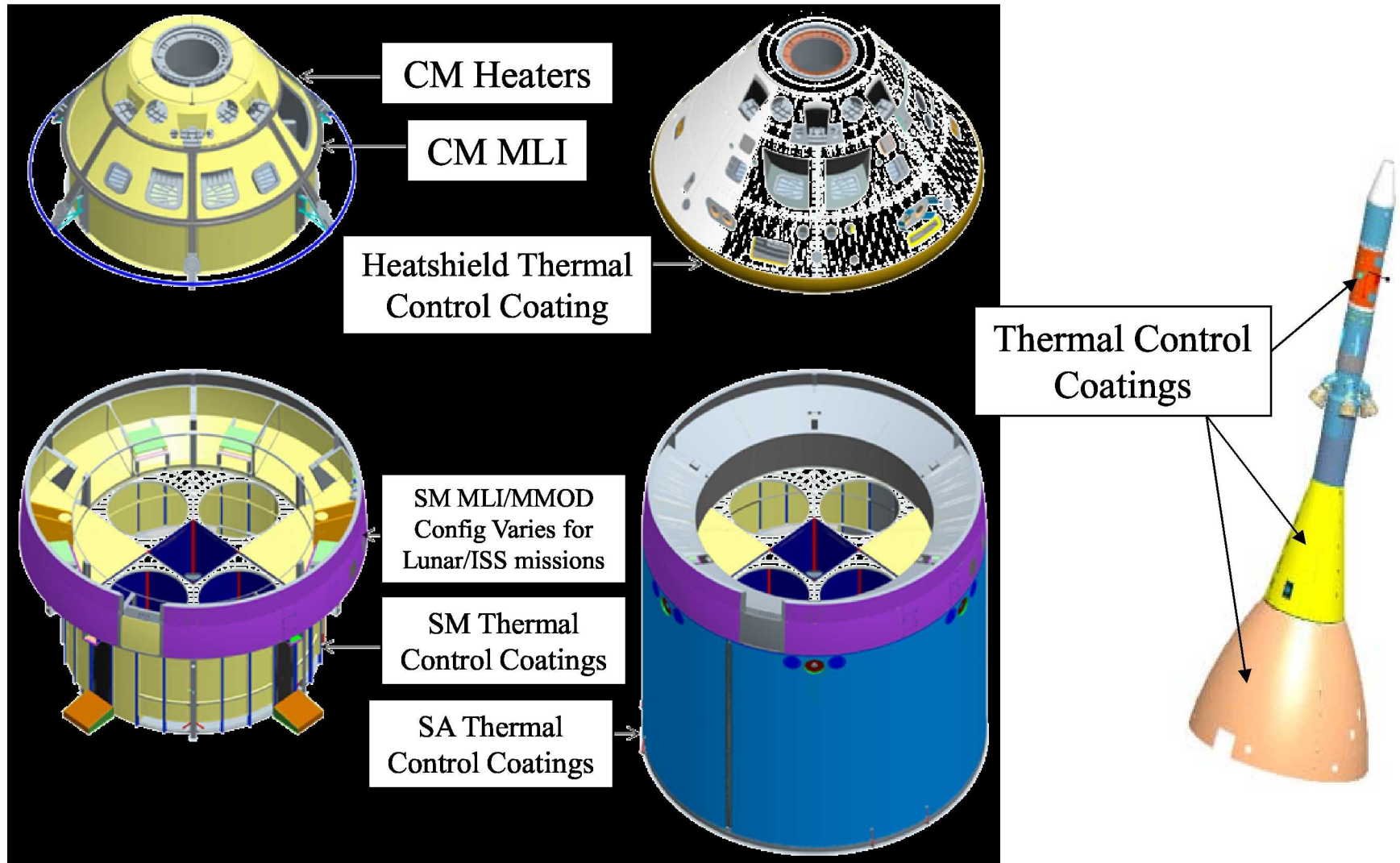


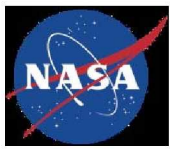


Orion PTCS Hardware



Crew Exploration Vehicle Project Office

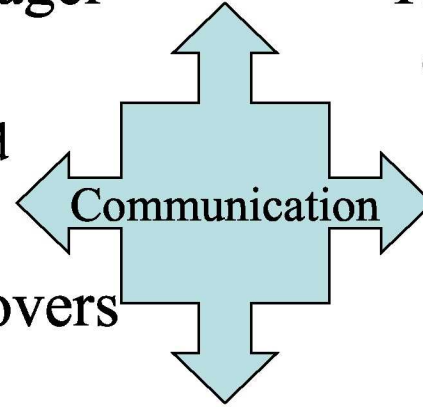




Orion PTCS Team



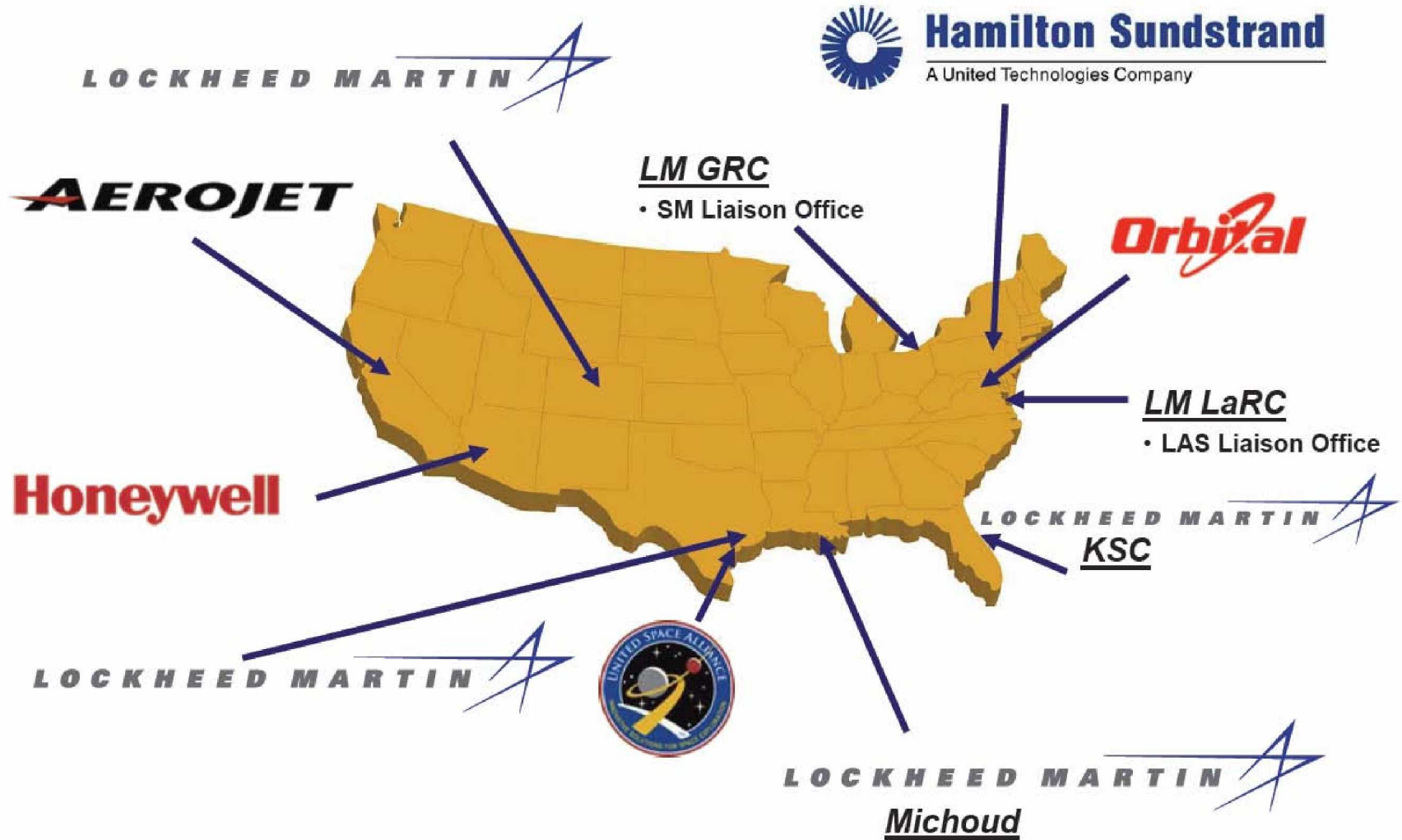
- NASA
 - PTCS System Manager
 - CM PTCS Lead
 - SM/SA PTCS Lead
 - LAS PTCS Lead
 - System Manager covers both analysis and hardware
- LM – Prime Contractor
 - Thermal Analysis Lead
 - LM Denver is primary contractor team
 - Subcontractors include:
 - Paragon: radiators
 - Orbital: LAS
 - Hamilton: ATCS
 - Aerojet: Thrusters, main engine
 - Honeywell: Avionics
 - PTCS Hardware Lead
 - LM Denver

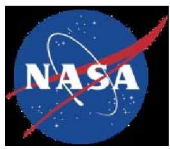


Internal and external communications are essential and challenging

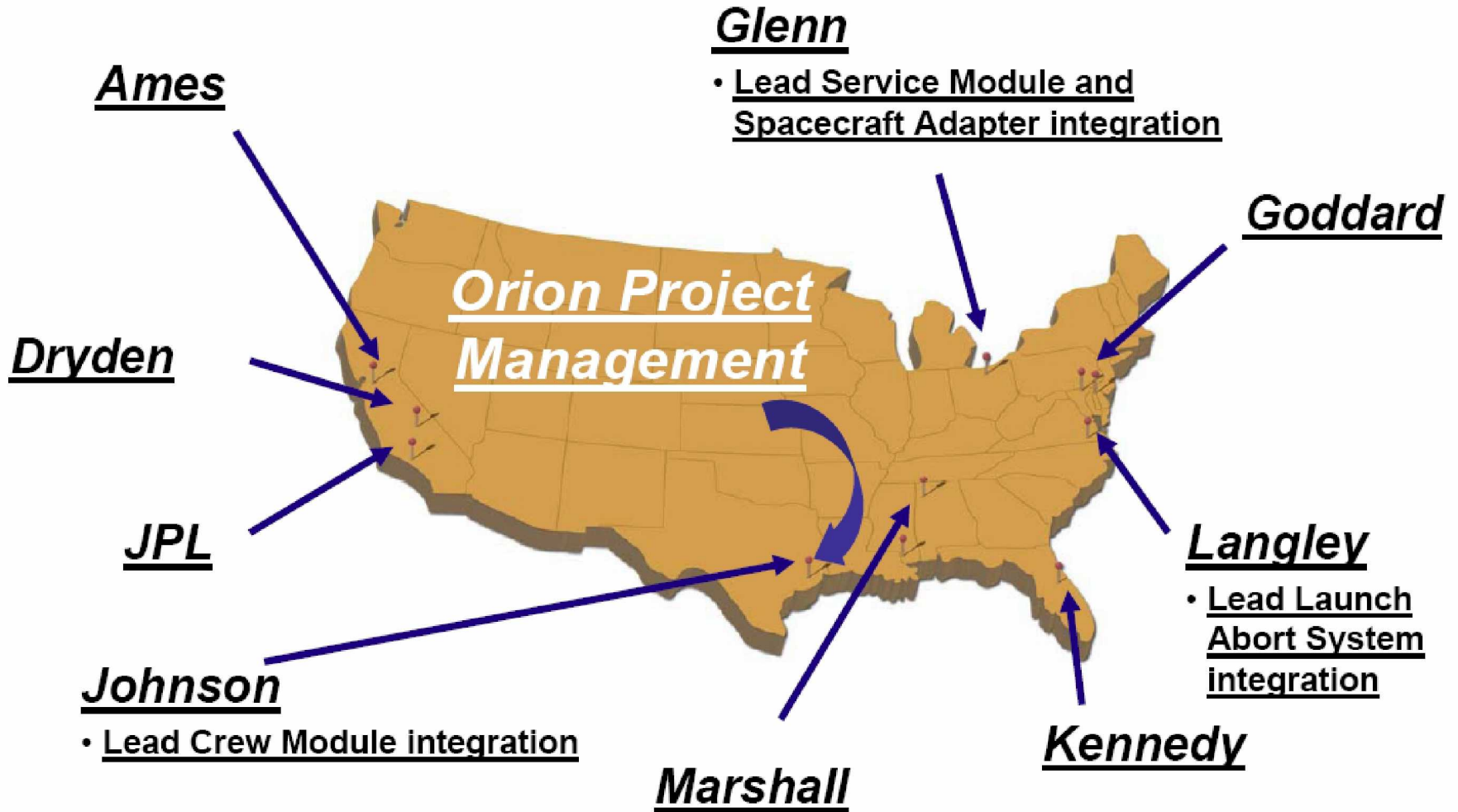


LM Contractor Team Locations



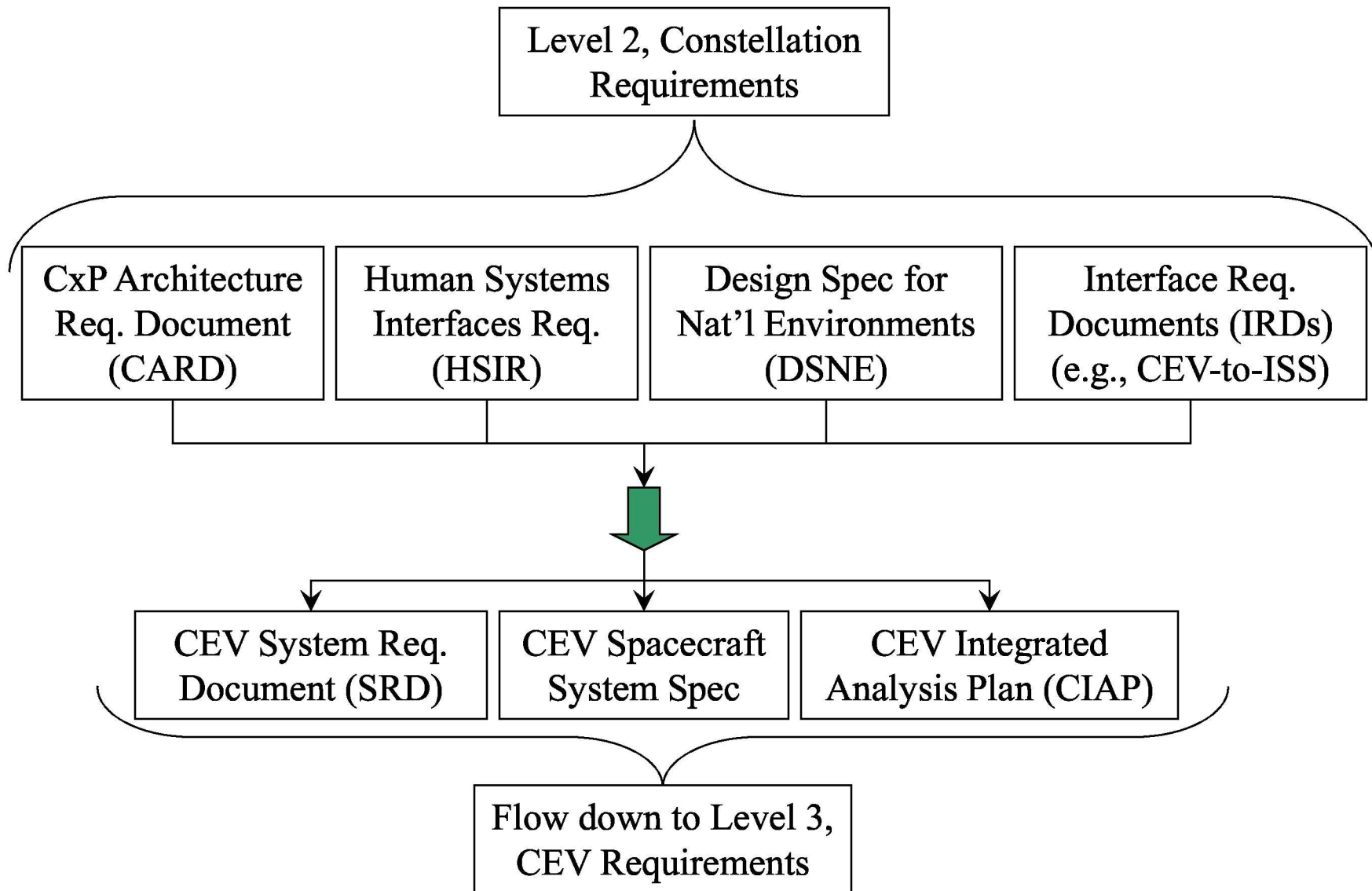


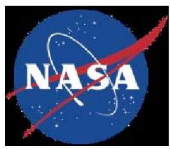
NASA Center Participation





Orion PTCS Overview Requirements





Requirements Examples



- From the CARD
 - The Constellation Architecture shall meet its requirements during and after exposure to the environments defined in CxP 70023, Constellation Architecture Design Specification for Natural Environments (DSNE).
- From the CEV SRD:
 - The CEV shall meet its functional and performance requirements during and after exposure to the environments defined in the CxP 70023, Constellation Program Design Specification for Natural Environments (DSNE), Sections 3.1, 3.2, 3.3, 3.5, 3.6 and 3.7.
- The HSIR (also mimicked in the CEV SRD) has several specific thermal items:
 - Touch Temperature limits
 - Condensation prevention on pressurized surfaces



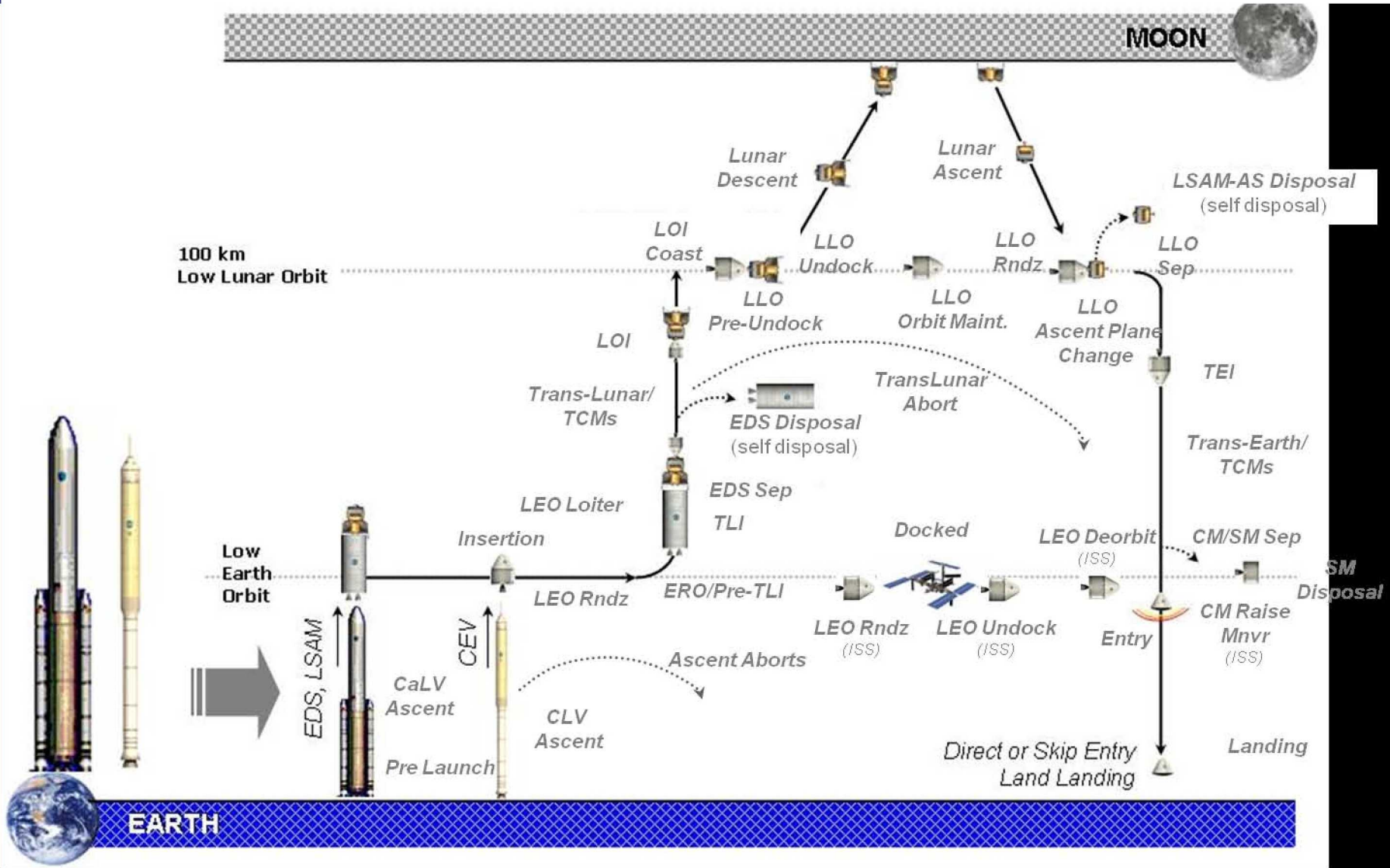
Orion PTCS Overview DRMs



- Design Reference Missions
 - ISS missions
 - Crew Exchange (up to 4 crew members)
 - Cargo/Resupply (uncrewed)
 - 6 month duration
 - Low Lunar Orbit (LLO) Sortie missions
 - Low Earth Orbit (LEO) ... transit ... Short-term Lunar surface excursion ... transit ... re-entry
 - Up to 4 crew
 - LLO Outpost missions
 - LEO ... transit ... Extended Lunar surface excursion ... transit ... re-entry
 - Up to 4 crew



Orion Mission Summary



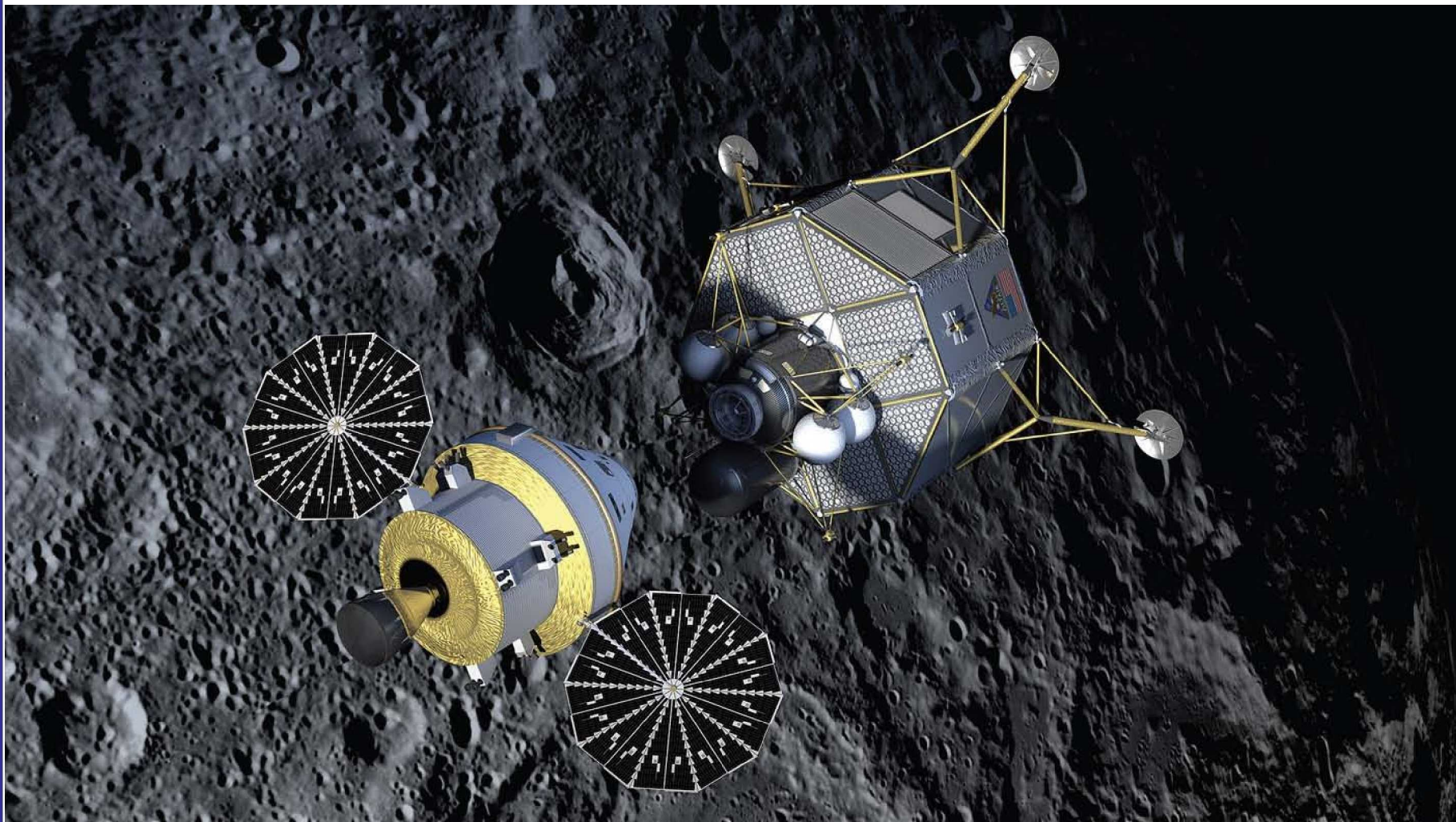


Orion Approaching the ISS





Orion and Altair in LLO





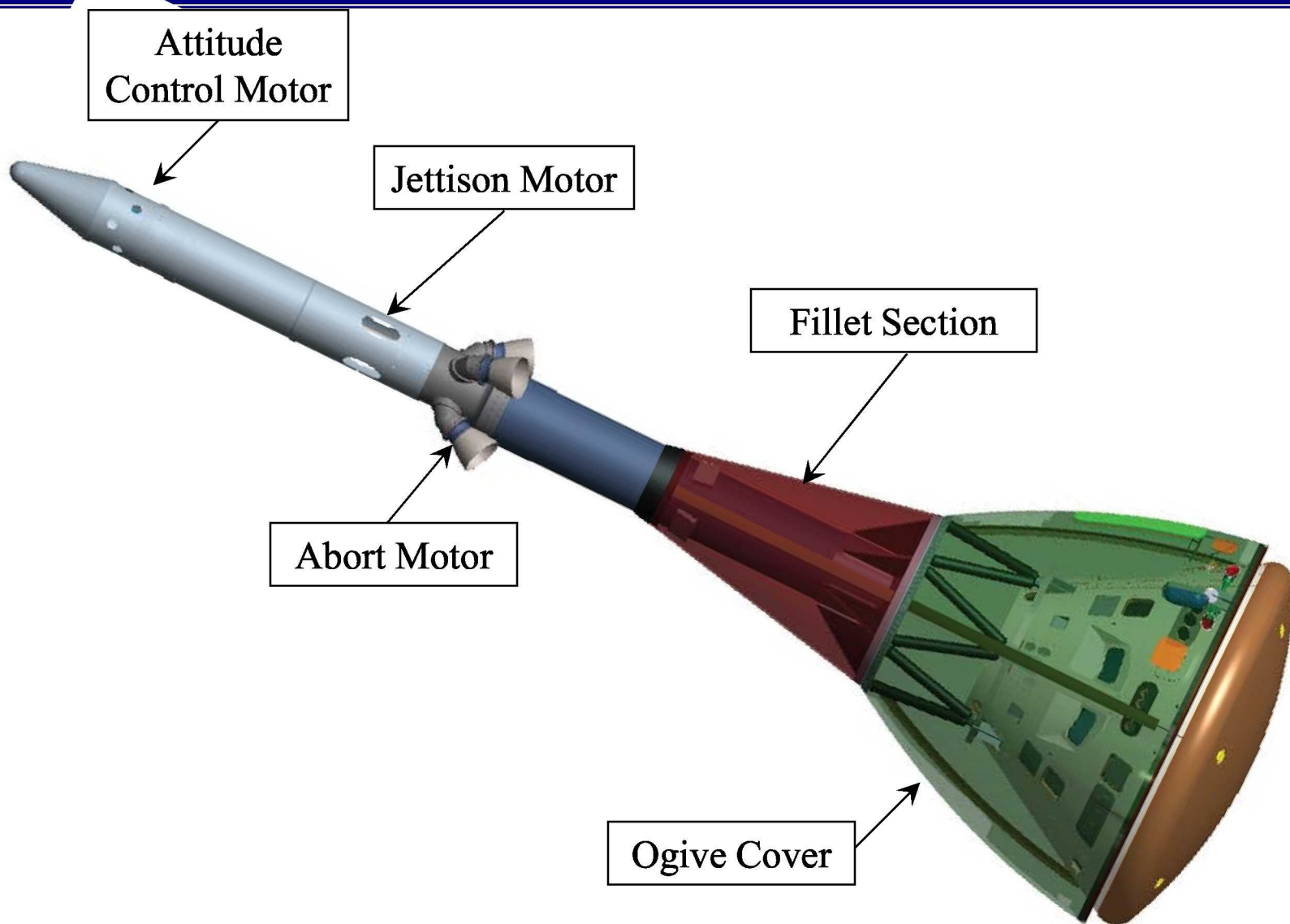
General LAS Description



- Launch Abort System
 - Main Purpose: Provide crew escape from catastrophic failure during early ascent phase.
 - Abort motors
 - Extract crew from hazard
 - Jettison motors
 - Used to remove LAS from CM
 - Ogive Cover
 - Protects CM surface from debris and ascent heating



LAS Image





LAS Images





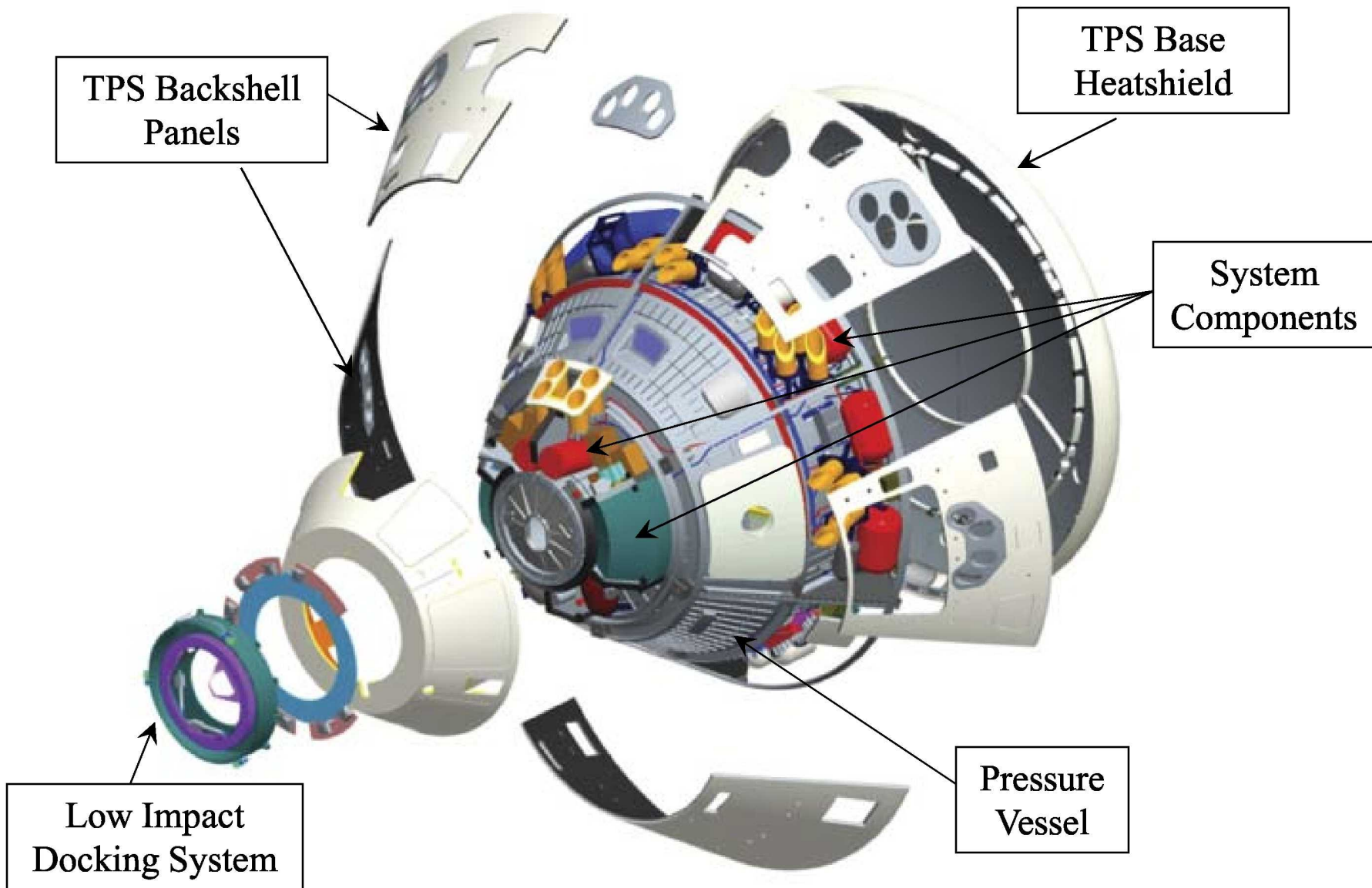
General CM Description



- Crew Module
 - Main Purpose: Provides living quarters for crew and re-entry capability
 - Thermal Protection System (TPS)
 - Backshell – conic section with penetrations
 - Heatshield – spherical base section and “shoulder region”
 - Pressure Vessel (PV)
 - Provide habitable volume and contains most avionics/electronics
 - Unpressurized area between TPS and PV houses some components
 - e.g. - Landing/Recovery (chutes), Power, Life Support (tanks), Propulsion (tanks/thrusters), Active Thermal Control (plumbing, coldplates)
 - Docking System
 - Low Impact Docking System (LIDS) being developed a Government Supplied Equipment.

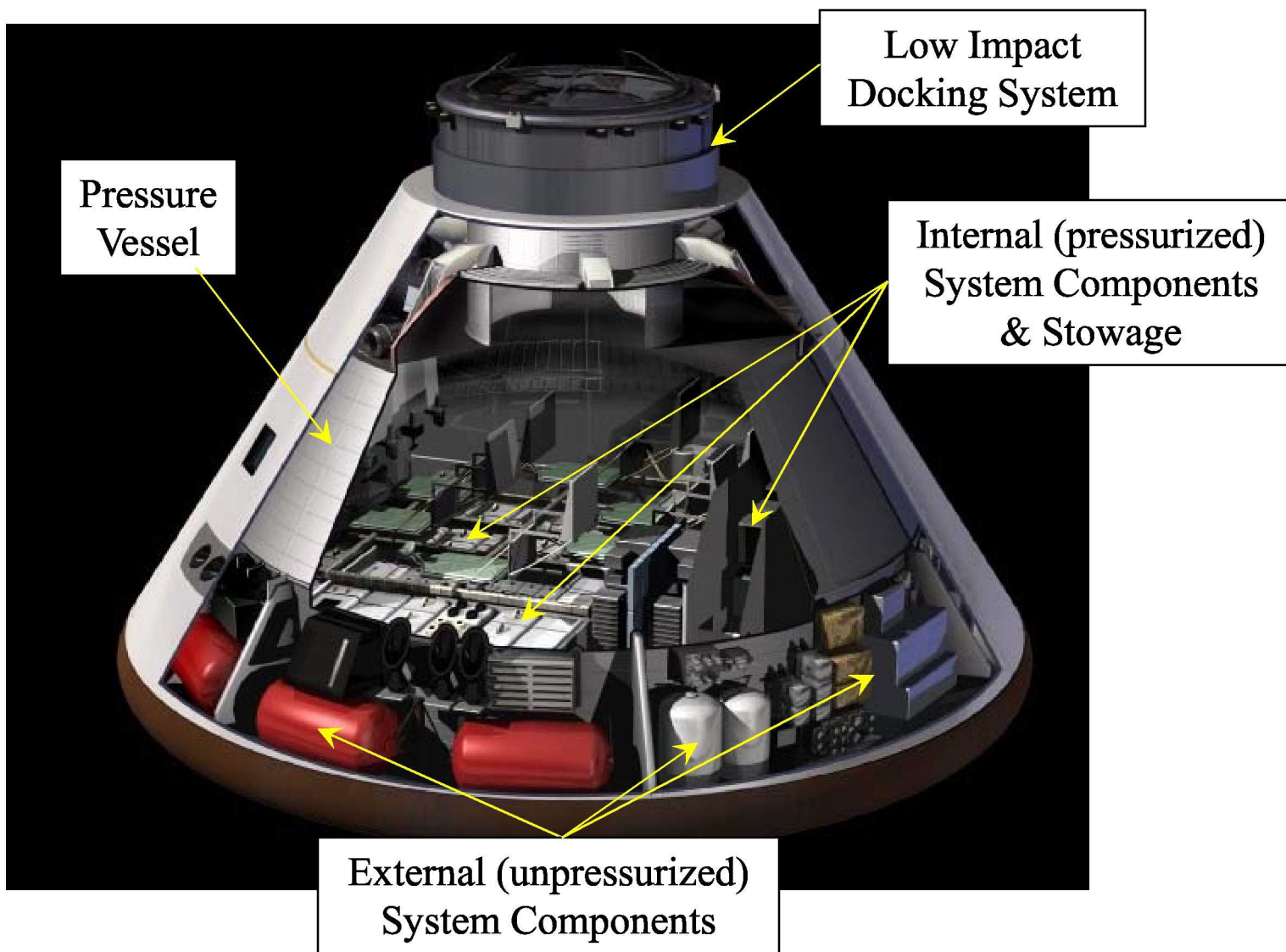


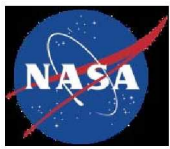
Exploded View of CM





Cutaway View of CM





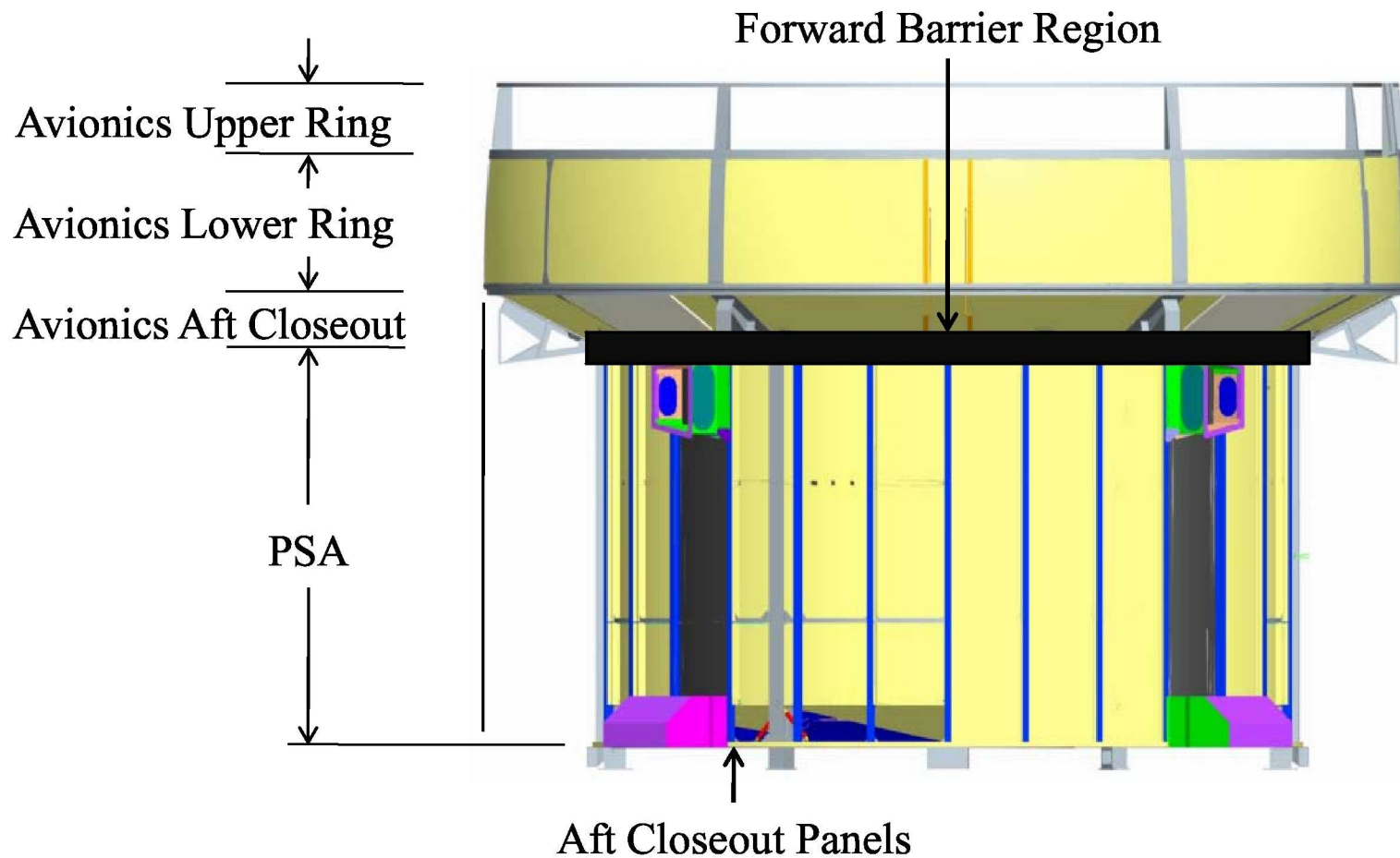
General SM Description

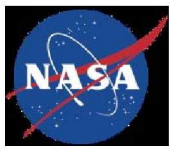


- Service Module
 - Main Purpose: Supplies propulsion, attitude control, power generation, heat rejections, and communications for the majority of the mission.
 - Note that the SM is discarded during re-entry, so each mission flies a brand new SM.
 - Radiators
 - Provide heat rejection of waste heat acquired from components in the CM and SM.
 - Prop tanks/thrusters & plumbing
 - The Prop system tanks, thrusters, and plumbing have an extensive heater system for temperature control.
 - Avionics ring
 - Mounts avionics/electronics for SM or overflow from the CM.

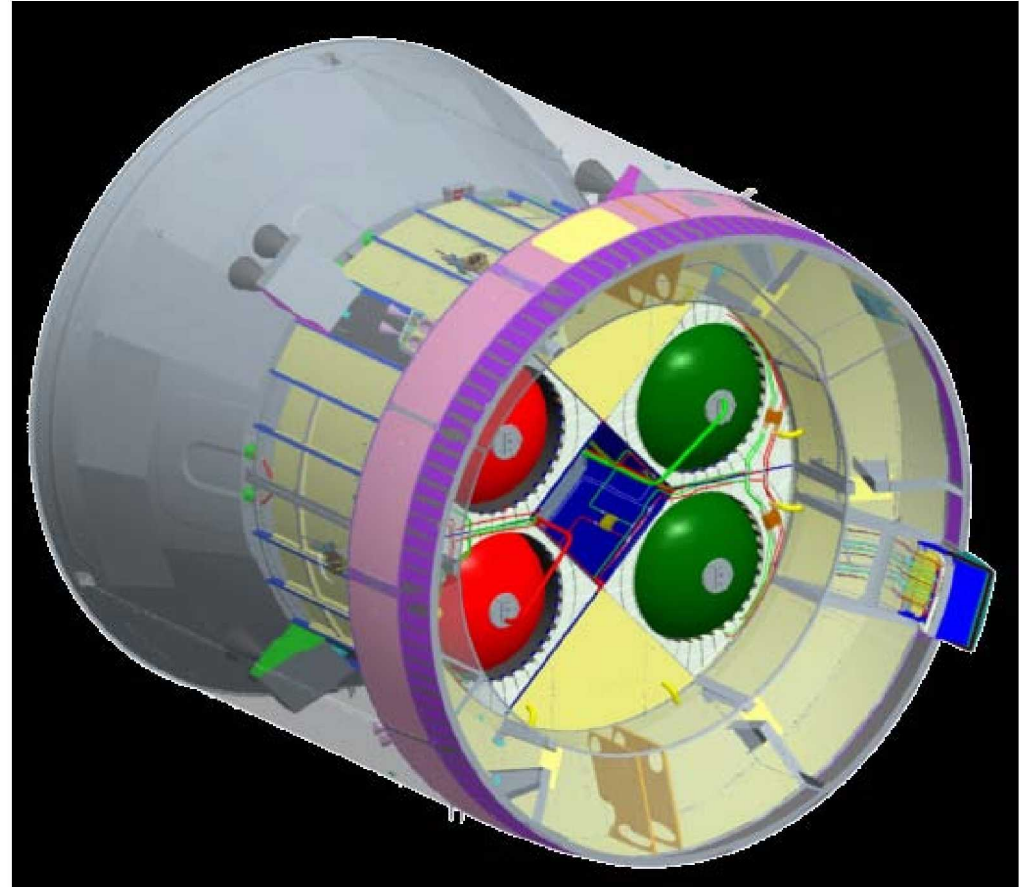
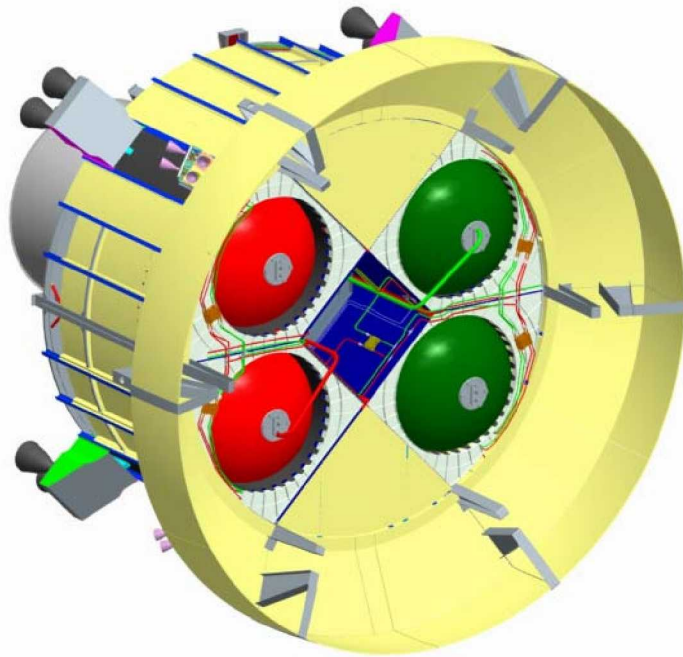


Service Module Images





Service Module Images





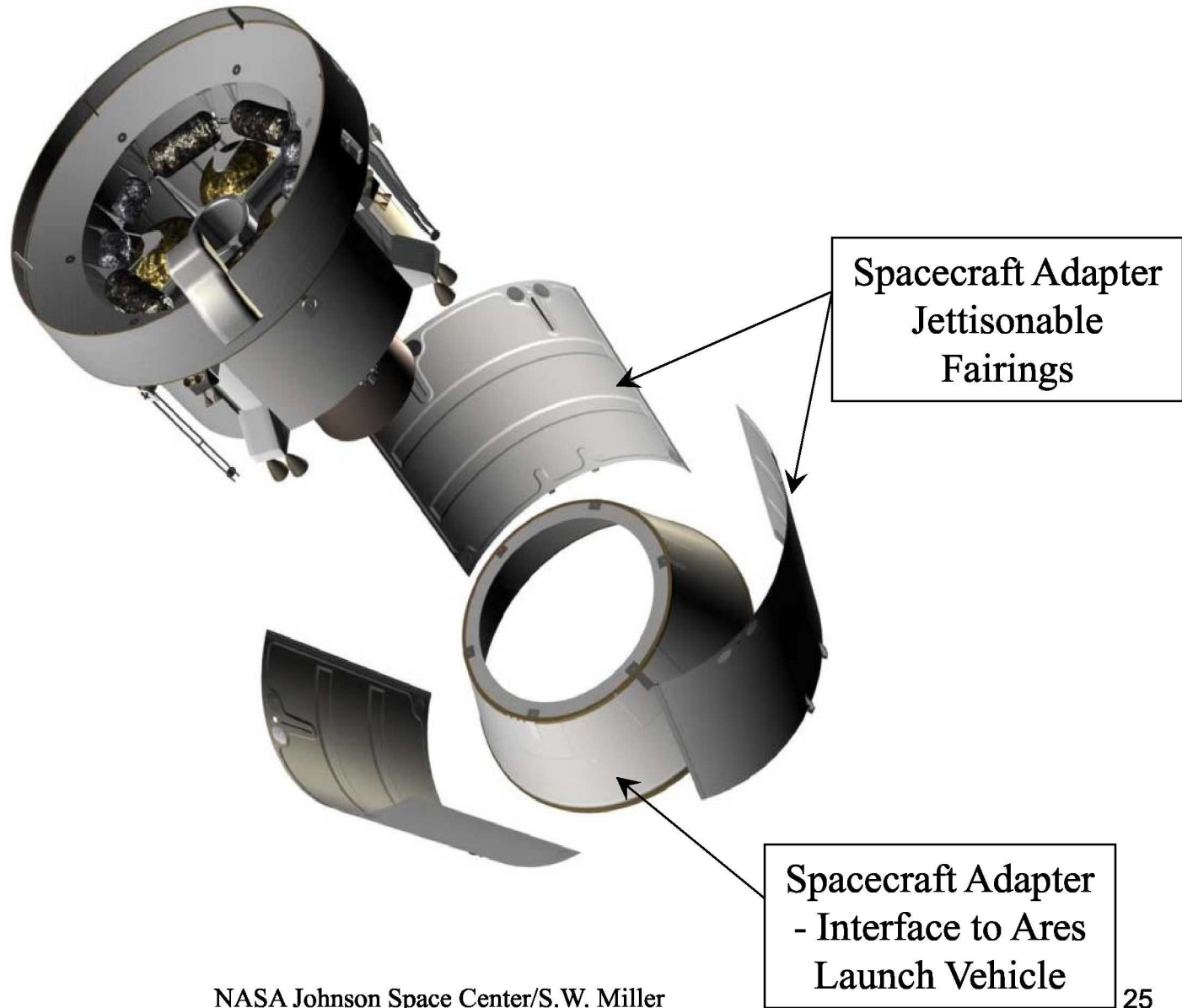
General Spacecraft Adapter Description



- **Spacecraft Adapter (SA)**
 - **Main Purpose:** Provides interface between Orion and Ares vehicles
 - **Jettisonable Fairings**
 - Protect radiators, solar arrays, and high gain antenna from ascent heating loads
 - The three panels are jettisoned seconds before LAS jettison.
 - **Ares Launch Vehicle Interface**
 - Structural interface connecting Orion to Ares
 - Also contains separation mechanism and umbilicals allowing Ares to communicate with Orion
 - The SA separates from Orion at Ares burnout



Spacecraft Adapter Image





Orion PTCS Overview – Natural Environments



- Two main documents define the CEV natural environments:
 - Design Specification for Natural Environments (DSNE, CxP 70023)
 - Natural Environments Definition for Design (NEDD, CxP 70044)
- The CEV on-orbit environments are currently split into 3 separate phases:
 - Transit
 - LEO
 - LLO



Transit Environments



- Simplest of the three phases (from a natural environments perspective!) ... assumes planetary effects (albedo and Outbound Longwave Radiation (OLR)) are negligible.
- We have chosen to use the minimum and maximum solar constants defined in the NEDD
- Hot Environment

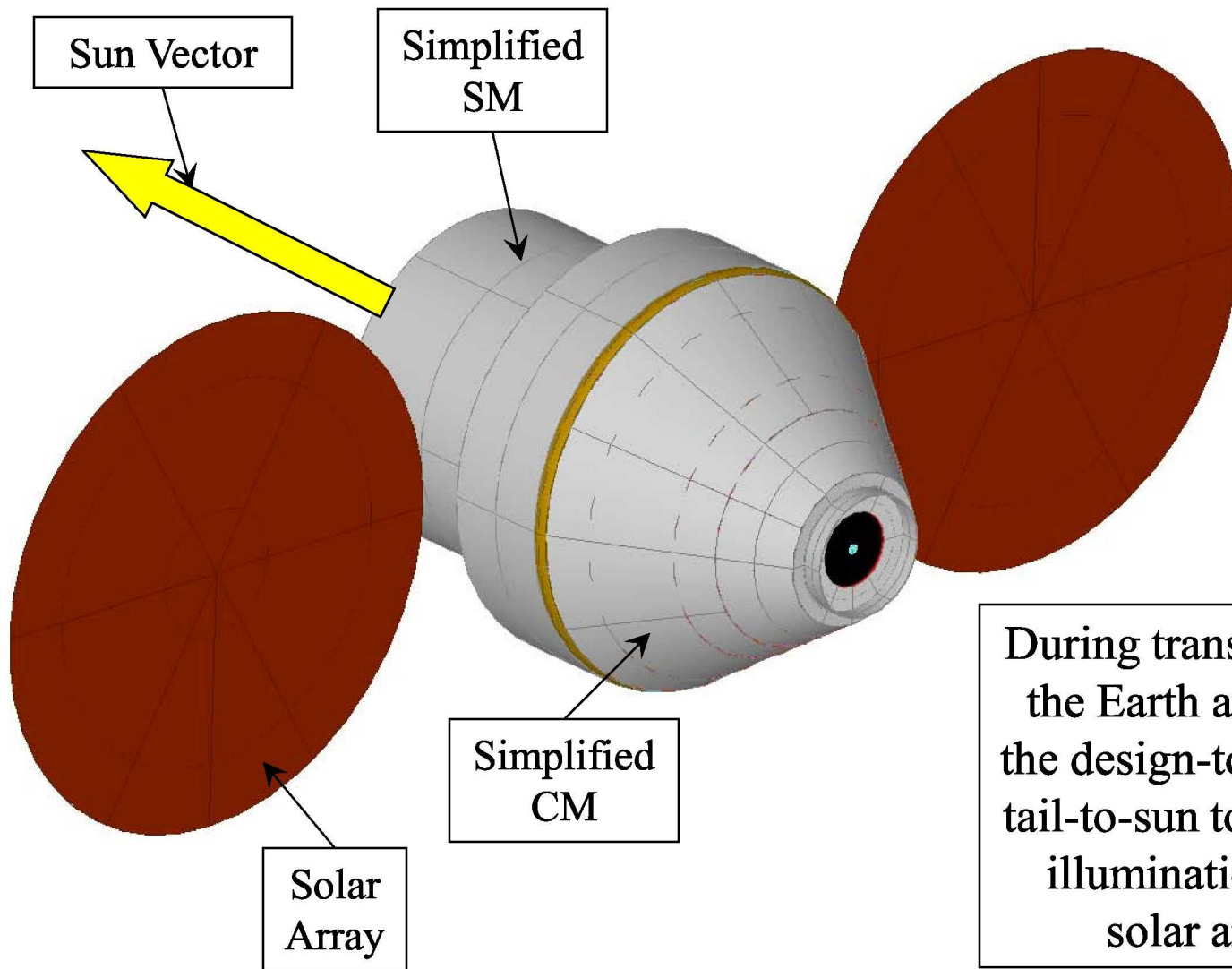
Solar Constant	451.2 BTU/Hr/ft ² (1422 W/m ²)
Albedo	0
OLR	0 BTU/Hr/ft ²

- Cold Environment

Solar Constant	417.2 BTU/Hr/ft ² (1315 W/m ²)
Albedo	0
OLR	0 BTU/Hr/ft ²



CEV in Tail-to-Sun Transit Case



During transit between the Earth and Moon, the design-to attitude is tail-to-sun to allow full illumination of the solar arrays.



LEO Environments



- In Low Earth Orbit, the Solar Flux is readily defined in the DSNE. However, the albedo and OLR are defined in pairs.
 - The pairs account for the fact that the coldest (or hottest) albedo and coldest (or hottest) OLR do not occur simultaneously.
 - There are also averaging periods which neutralize short-term extremes.
 - Must be cognizant of the vehicle/component's thermal time constant.
 - The pairs are also categorized by orbital inclination.
- A solar zenith angle (SZA) correction factor must also be applied to the albedo.
 - The NEDD defines the SZA correction as a 4th order polynomial
 - The equation can be directly incorporated into Thermal Desktop.



LEO Environments, Continued



- The Orion CEV PTCS analysis uses the following assumptions:
 - An Averaging Time sufficient for the model's thermal time constant is used when estimating the albedo and OLR
 - The Combined Minimum (or Maximum) albedo/OLR pair is appropriate given the thermal model's optical property sensitivities.
 - Note that if the analyst feels their model is more sensitive to either the solar or infrared spectrum, then he/she should refer to the DSNE/NEDD for different values.
 - The analyst assigns a value of True Anomaly = 0° to occur at orbital noon.
 - The solar zenith angle is defined by the following relationship
$$SZA = \cos^{-1}(\cos(\beta) * \cos(\nu))$$
 - Where β is the beta angle and ν is the true anomaly.



LEO Environments, Continued



- LEO Natural Environments for an ISS Hot Case

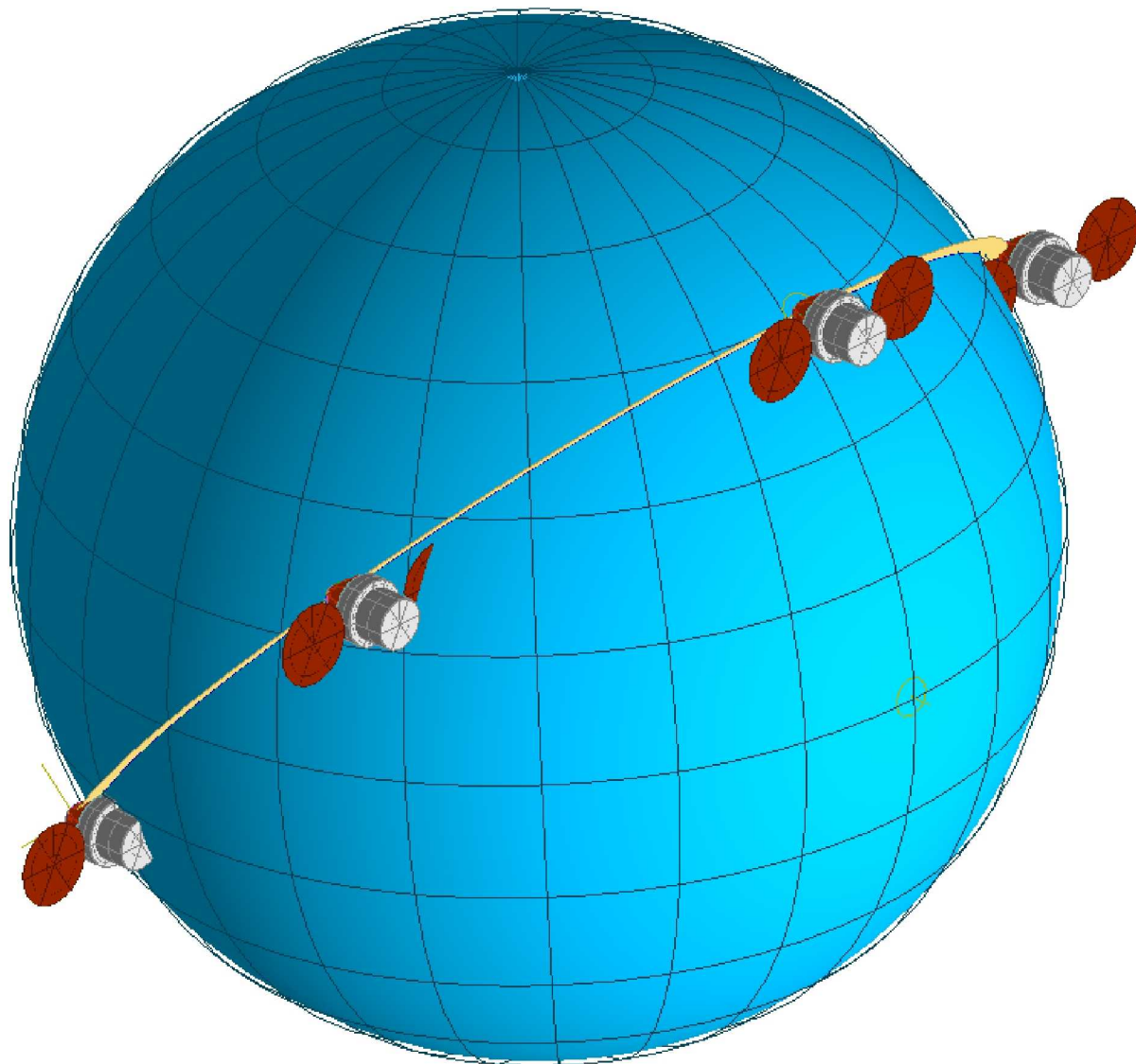
Solar Constant	448.6 BTU/Hr/ft ² (1414 W/m ²)
Albedo	0.28 + SZA Correction
OLR	81.9 BTU/Hr/ft ² (258 W/m ²)

- LEO Natural Environments for an ISS Cold Case

Solar Constant	419.5 BTU/Hr/ft ² (1322 W/m ²)
Albedo	0.17 + SZA Correction
OLR	68.9 BTU/Hr/ft ² (217 W/m ²)



CEV in Tail-to-Sun LEO, $\beta = -45^\circ$



Crew Exploration Vehicle Project Office



LLO Environments



- In Low Lunar Orbit, the solar constant and albedo are relatively straightforward, but the OLR is complicated.
 - The NEDD provides a formula for calculating the day-side lunar OLR. The formula requires:
 - The average albedo, \bar{a} , 0.15
 - The Solar Constant, S_o , at 1 AU, 1367 W/m²
 - The solar zenith angle, $\cos(i)$
 - The Sun-Moon distance, R_L , in AU

$$OLR_{Day-Side} \approx \frac{(1 - \bar{a}) S_o \cos(i)}{R_L^2}$$

- On the night-side of the moon, the OLR is calculated from:

$$OLR_{Night-Side} \approx \epsilon \sigma T_s^4$$

- ϵ is the lunar emissivity
- σ is the Stefan-Boltzmann constant.
- T_s is the lunar surface temperature



LLO Environments, Continued



- LLO Natural Environments for a Hot Case

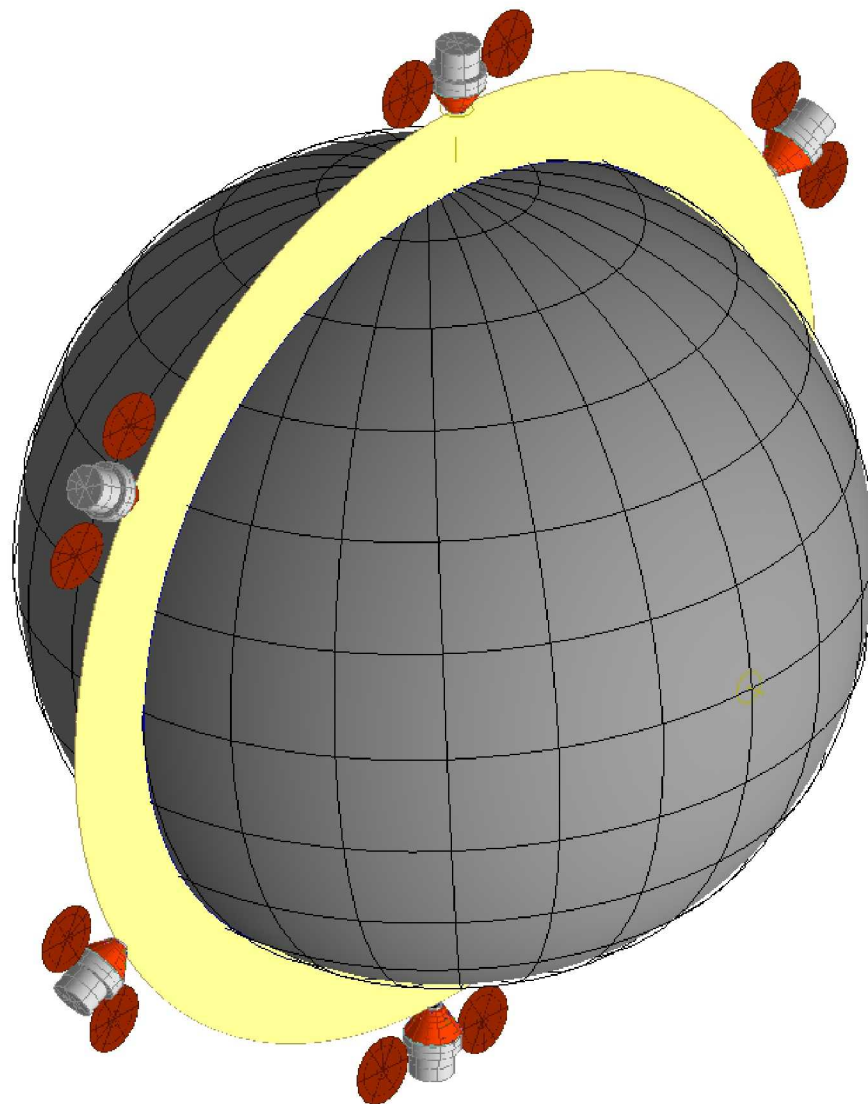
Solar Constant	451.2 BTU/Hr/ft ² (1422 W/m ²)
Albedo	0.2
OLR Day-Side	383cos(<i>i</i>) BTU/Hr/ft ² (1208cos(<i>i</i>) W/m ²)
OLR Night Side	11.8

- LLO Natural Environments for Cold Case

Solar Constant	417.2 BTU/Hr/ft ² (1315 W/m ²)
Albedo	0.07
OLR Day-Side	355cos(<i>i</i>) BTU/Hr/ft ² (1118cos(<i>i</i>) W/m ²)
OLR Night Side	3.7



CEV in Nose Nadir LLO, $\beta = -85^\circ$





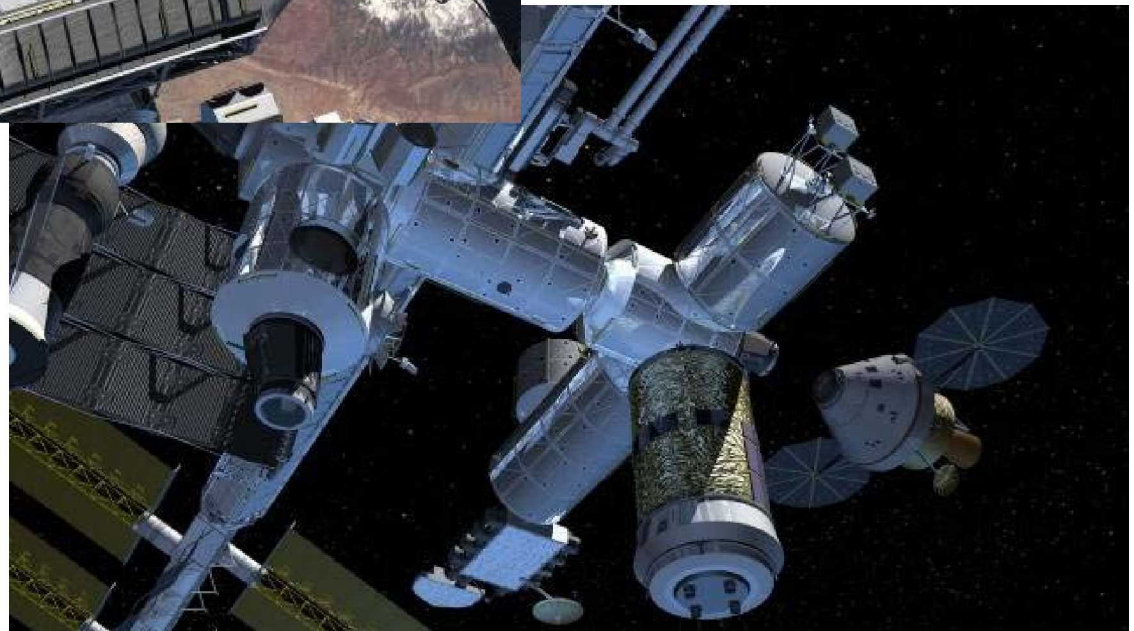
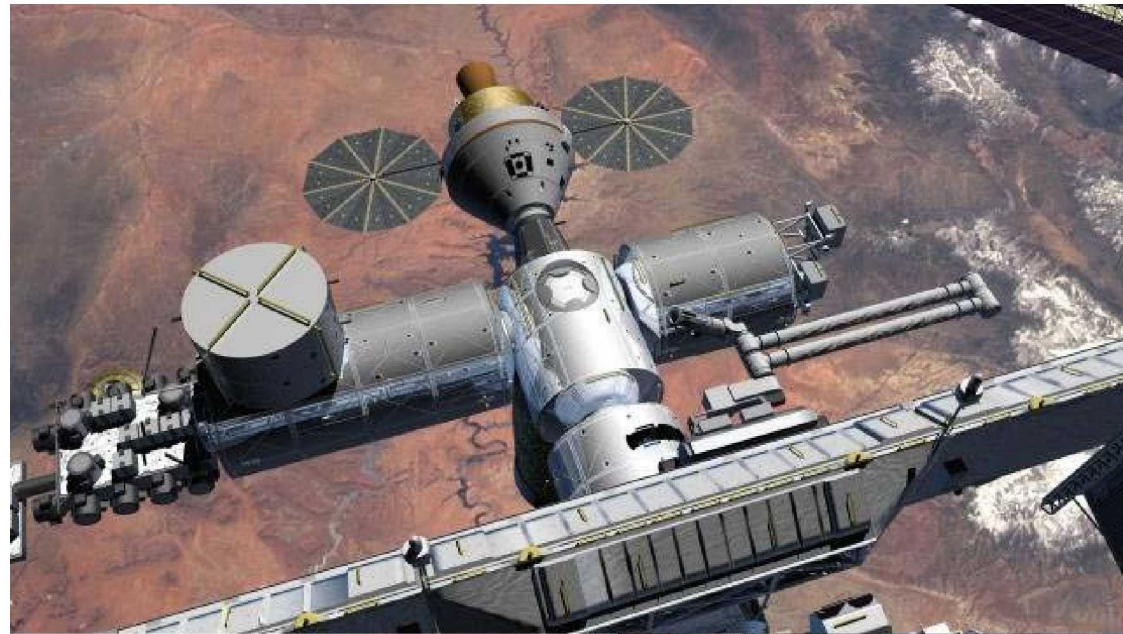
Other CEV Environments

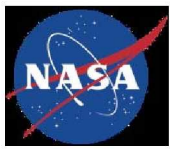


- Pre-launch
- Ascent Aeroheating liftoff to orbit injection (continuum and non-continuum heating)
 - Nominal ascent
 - Abort back to earth
 - Abort to orbit
 - Aeroheating
- Mated to ISS
- Re-entry Heating
 - Lunar return is based on a skip re-entry
- Post-landing



Images of CEV Mated to ISS at Node 2



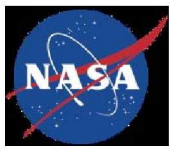


Orion PTCS Overview

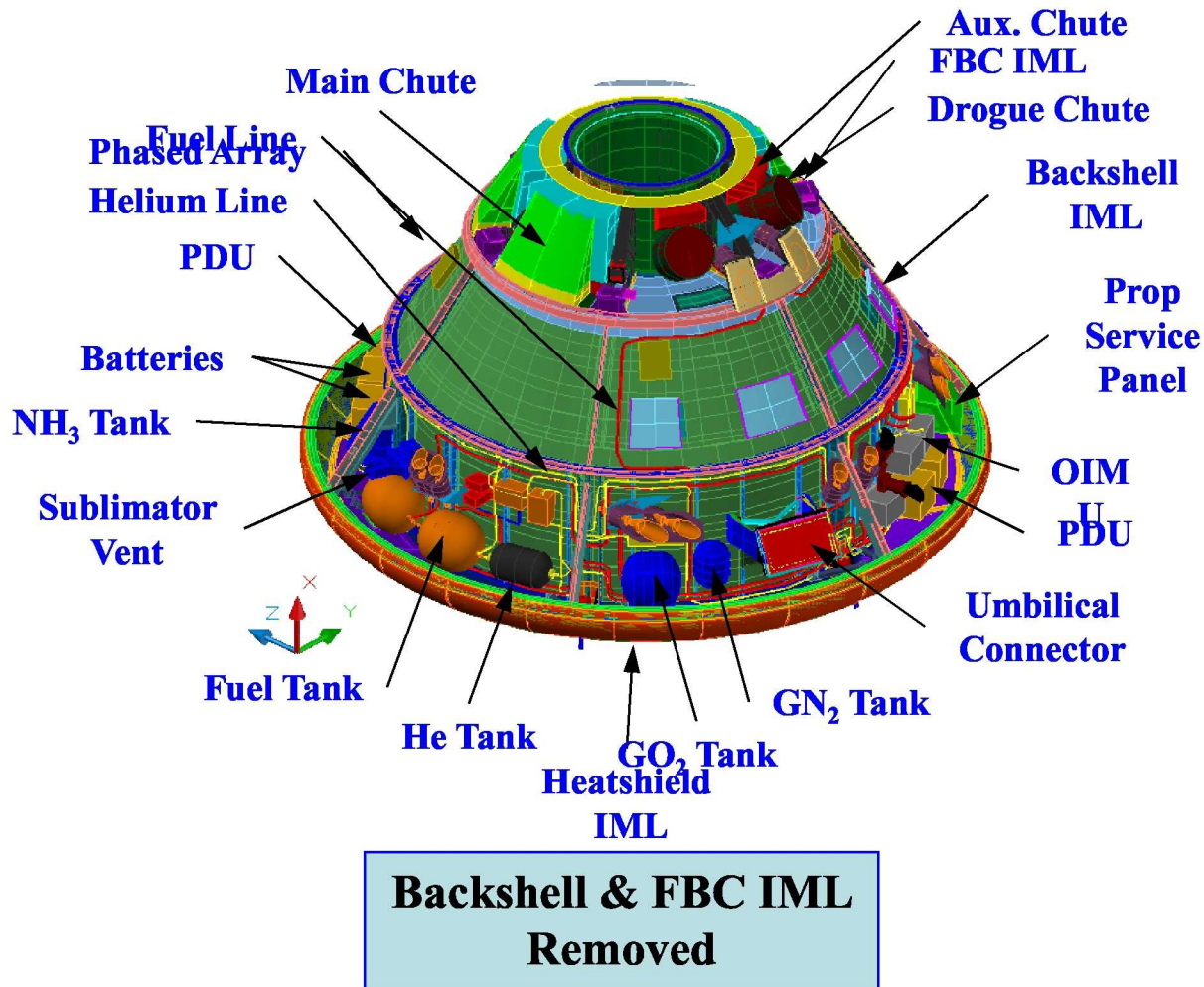
Thermal Models



- Thermal Models
 - Both NASA and LM are using Thermal Desktop 5.2 and AutoCAD 2008
 - Most subcontractors are also using these programs
 - Results in an efficient model exchange, no model conversion
 - Generated an unofficial Orion “user group” where modeling techniques, approaches, and help are shared
 - LM has developed detailed PDR-level integrated thermal model
 - Currently on Design Analysis Cycle 3.
 - Will modify and update model as design matures
 - DAC models will be used for design verification
 - NASA uses DAC models for parametric, operational, and functionality studies

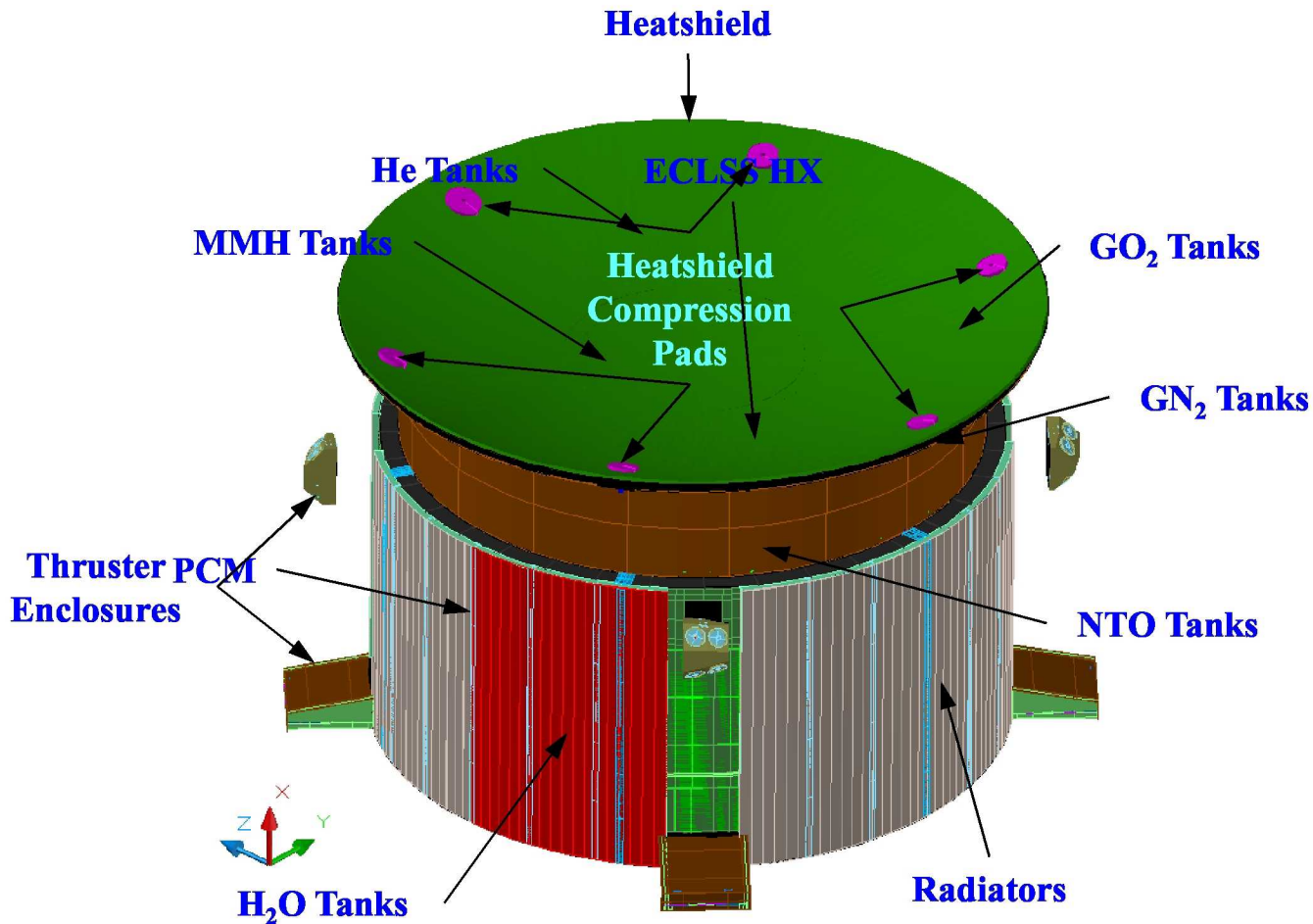


Detailed CM Integrated Thermal Model





Detailed SM Integrated Thermal Model



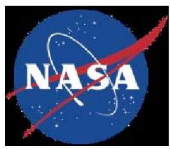
IML, Radiators and Heatshield



Thermal Model Evolution



- Current Thermal Models are at a PDR level
 - Over 25,000 nodes
 - Most components are represented as a single node with the appropriate mass, internal power dissipation (where applicable), and best-guess material/optical properties.
- As the design matures, component models will be refined
 - Subcontractors will deliver component thermal models
 - A detailed model to completely describe the component
 - And a smaller, simplified model to integrate into the system level model.
 - These will be correlated to test data



Thermal Model Evolution, Cont.



- At the integrated system level:
 - Correlated, simplified component models will be incorporated.
 - TPS Backshell penetrations and similar details will be incorporated
 - i.e., solar arrays, SM main engine, plumbing routing, component attachments, etc.
 - Development testing of specific thermal connections may be performed to bound particular parameters.
 - The integrated model will then be correlated to system Thermal Balance and Qual test (thermal vacuum) data.
- The goal is to have a fully certified PTCS model for use for testing and on-orbit predictions.
 - If the system-level model predicts violations then the more detailed component models can be used.
 - Will use the certified model for acceptance test predictions, orbital flight test predictions, and mission timelines.



Passive Thermal Challenges



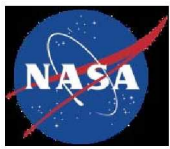
- LAS Thermal Areas of Interest/Challenges
 - Propellant temperatures
 - The extreme cold case at KSC make it difficult to keep the abort propellant within temperature limits during the transportation to the launch pad and pre-launch operations.
 - Communication box cooling
 - Components located in a region of the LAS without dedicated purge for cooling.



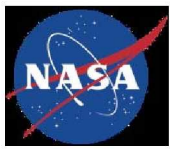
Passive Thermal Challenges, Cont.



- CM Thermal Areas of Interest/Challenges
 - Ascent Heating
 - After fairing jettison, the LIDS, avionics ring, and TPS backshell are exposed to aeroheating.
 - TPS/Pressure Vessel Heat Leak
 - Use a combination of heaters and active thermal control loops to prevent condensation on PV walls. Challenges include heater zoning and software control for both heaters and fluid loops.
 - Defining Heat Leak/Gain with Cabin Air
 - With the current ECLSS/ATCS design, that team requires information on the heat leak/gain from components and the PV into the air. Requires estimating heat transfer coefficients or thermal conductivity for different regions/zones of air in the vehicle. Challenges are for both on-orbit and post-landing



- SM Thermal Areas of Interest/Challenges
 - SM Prop Temperatures
 - The Prop team has identified a narrow temperature range for prop components. Requires a tight heater control band and thermal isolation from other SM components.
 - SM Radiator design and environments
 - The post-fairing jettison ascent aeroheating on the radiators limit heat rejection in the early flight phases.
 - LLO high OLR environment make radiator sizing difficult



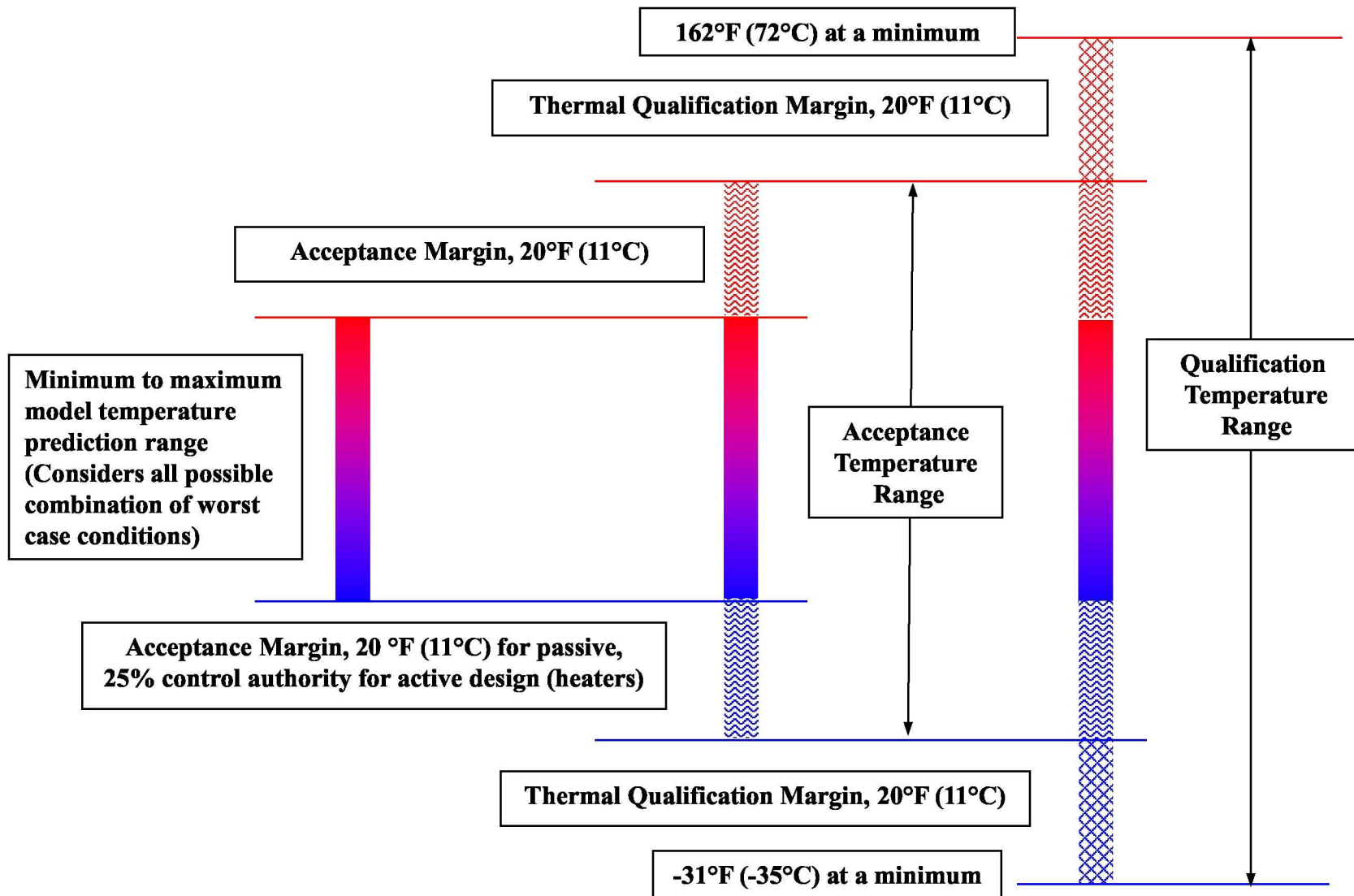
Orion PTCS Overview Testing



- Flight Testing – several early flight tests are planned
 - Pad Abort 1 and Ascent Abort 1 are the near-term tests.
 - Will demonstrate on-pad and max Q abort capability
- For thermal, the controlling test document is the Constellation Environmental Qualification and Acceptance Test Requirements (CEQATR)
 - It defines how thermal balance, thermal cycle, and thermal vac testing will be conducted.
 - This document is applicable to both the unit (box) and system (up to and including the full Orion vehicle) level for Qual and Acceptance tests.
 - Thermal test plans include provision for development testing, qual testing, and acceptance testing.



Qual/Acceptance Temperatures



Questions

