Crew Exploration Vehicle Composite Pressure Vessel Thermal Assessment

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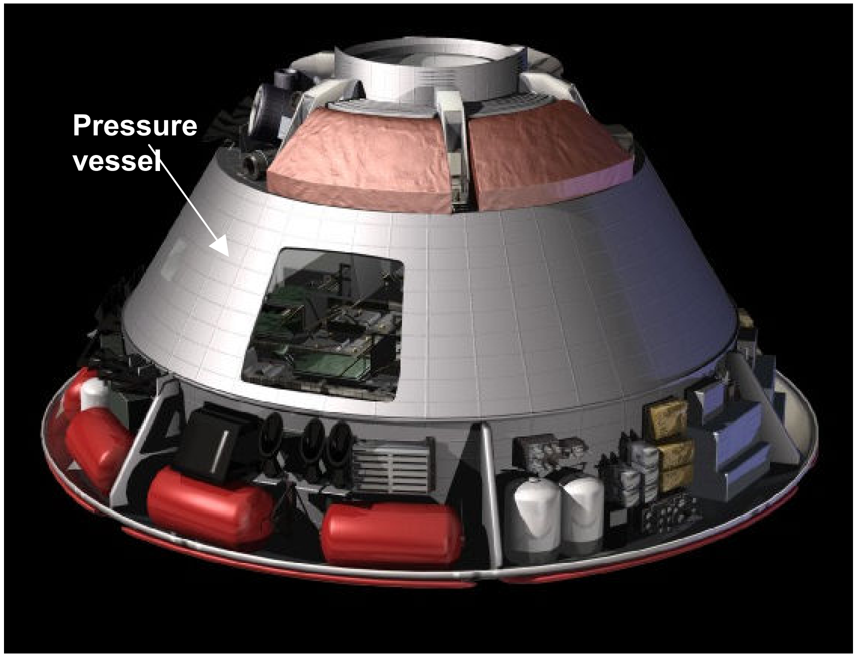
Presentation Contents

- Background
  - Thermal analysis of a composite pressure vessel (CPV) was undertaken in support of an NESC-sponsored pathfinder project
- Procedure
  - A finite element translation of the CPV was integrated into an existing CEV Thermal Math Model (TMM) based on the 605 baseline configuration
  - Four orbital cases have been analyzed
- Results
  - Graphical steady state temperature profiles
  - Steady state temperature in NASTRAN-compatible TEMP card format for direct input into a stress model
- Conclusion
  - A qualitative assessment of make-up energy and relevant recommendations are presented

Background

Orion CEV spacecraft

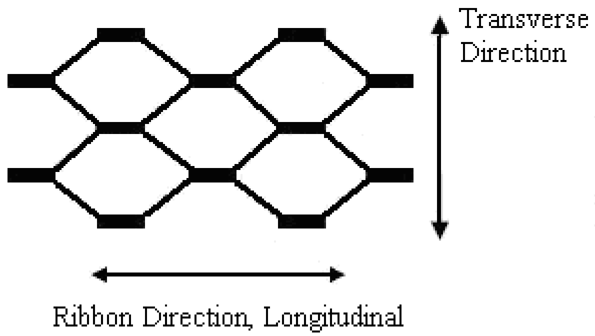
Orion CEV spacecraft with outer skin removed revealing pressure vessel

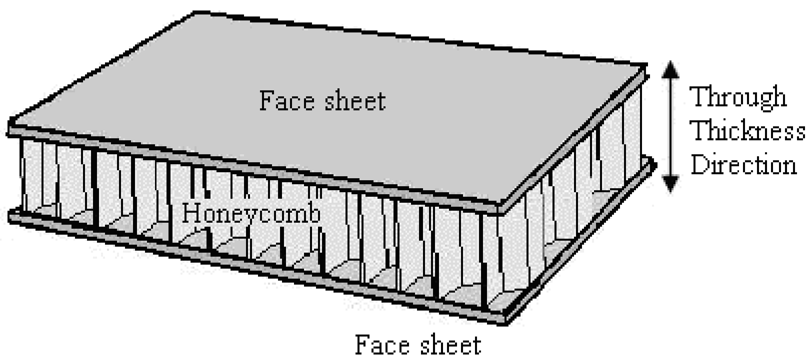


Background

- The composite pressure vessel cross section is composed of an inner and outer face sheet (FS), and honeycomb (HC) section
- The finite element translation of the CPV assumed shell elements for the CPV
- This neglects through-the-thickness temperature gradients
- This is not necessarily a valid assumption for the CPV

Honeycomb (HC), inner and outer face sheet (FS) configuration

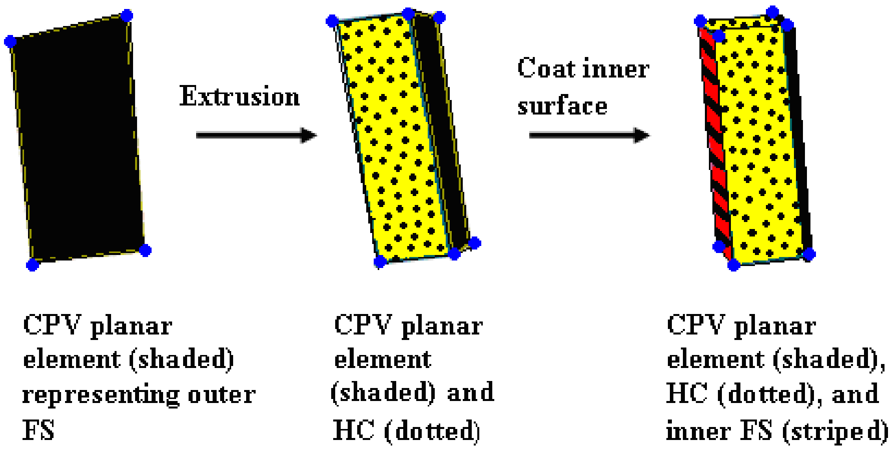




Thermal Math Model

- The planar shell surfaces were extruded into solid elements
- An aggregate HC/FS conductance was calculated using a JSC thermal math model
- This allows for through-the-thickness temperature gradients
- Calculated values are based on vented HC

Thermal Desktop pressure vessel model building procedure



Thermal Math Model

Optical Property Assumptions

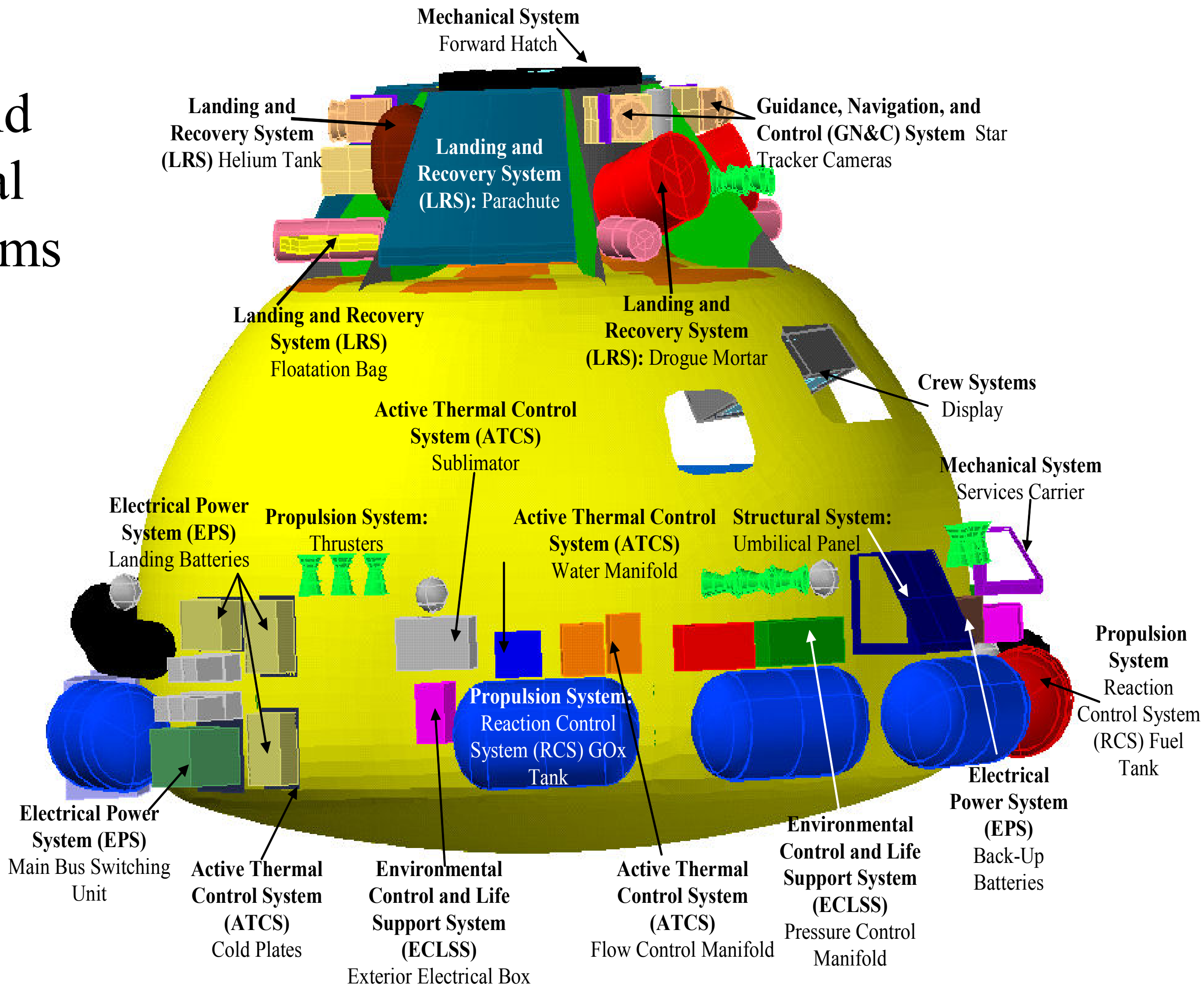
	Material Used	Solar Absorptivity, α	Infrared Emissivity, ε
TPS/Backshell Structure			
Outer BS	Reaction Cured Glass (RCG)	0.85	0.85
Outer HS	Reaction Cured Glass (RCG)	0.85	0.85
Inner FS	Titanium	N/A	0.2
CPV			
Inner FS	Tape (M55J)	N/A	0.72
Outer BS	Kapton Film, A Backing	N/A	0.71

Thermal Math Model

- Active Thermal Control System (ATCS)
- Avionics
- Communications
- Crew Systems
- Electrical Power
- Environmental Control and Life Support System (ECLSS)
- Guidance, Navigation, and Control (GN&C)
- Landing and Recovery System (LRS)
- Mechanical System
- Propulsion
- Structural

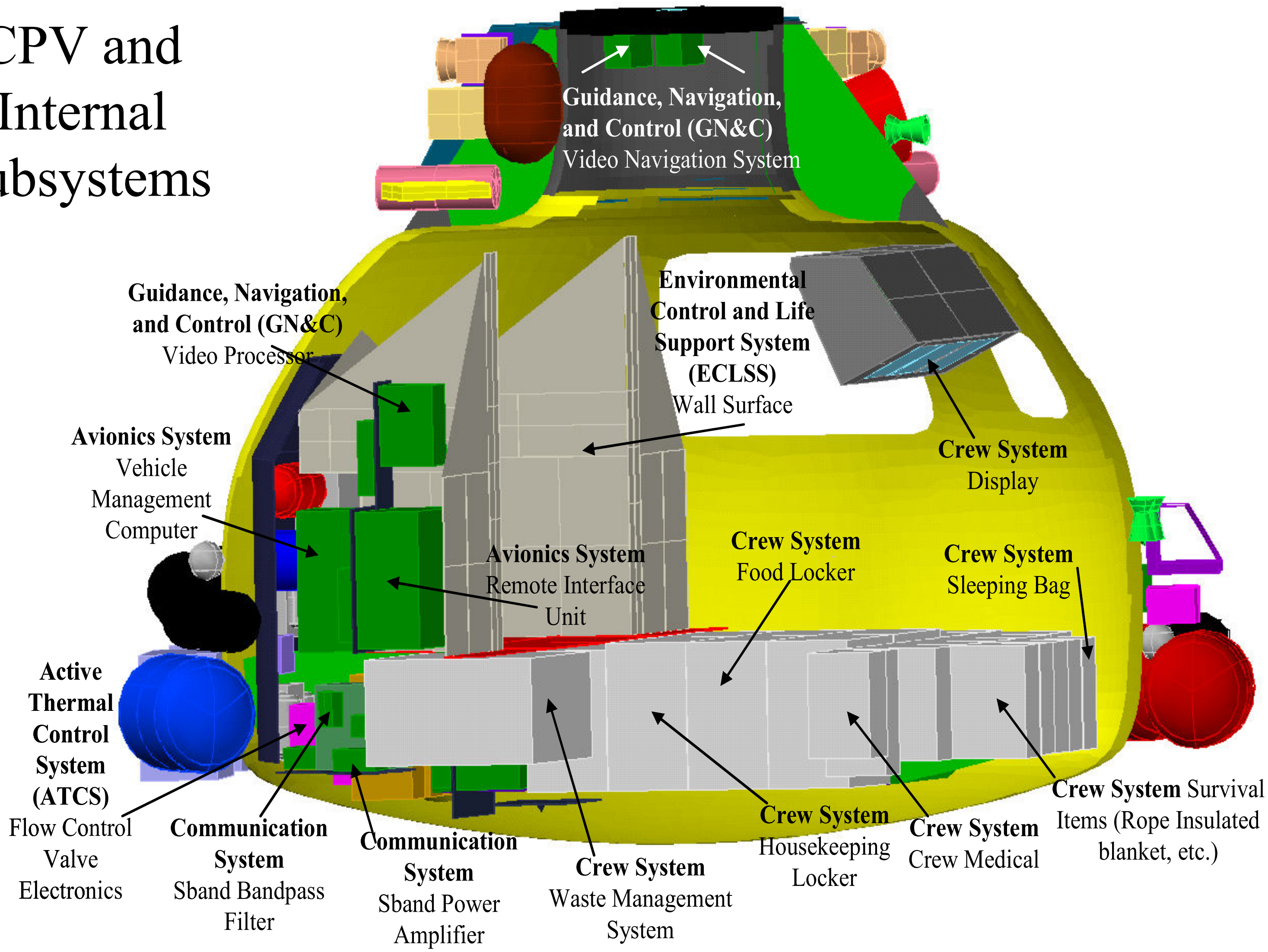
Thermal Math Model

CPV and External Subsystems



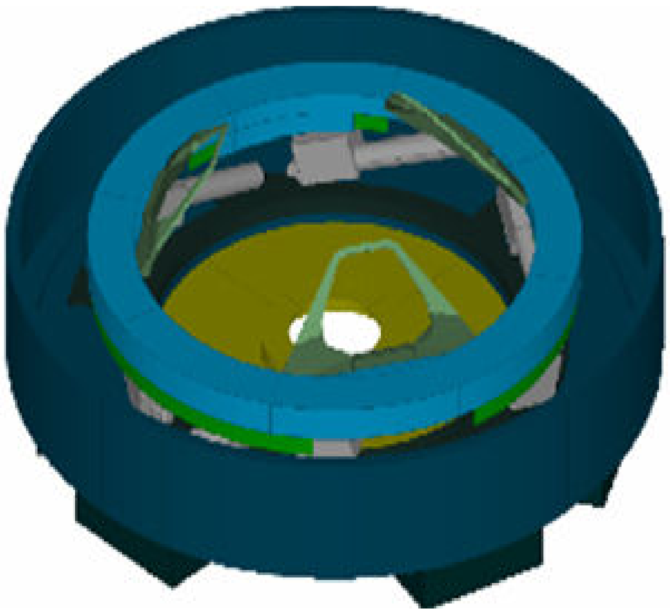
Thermal Math Model

CPV and Internal Subsystems

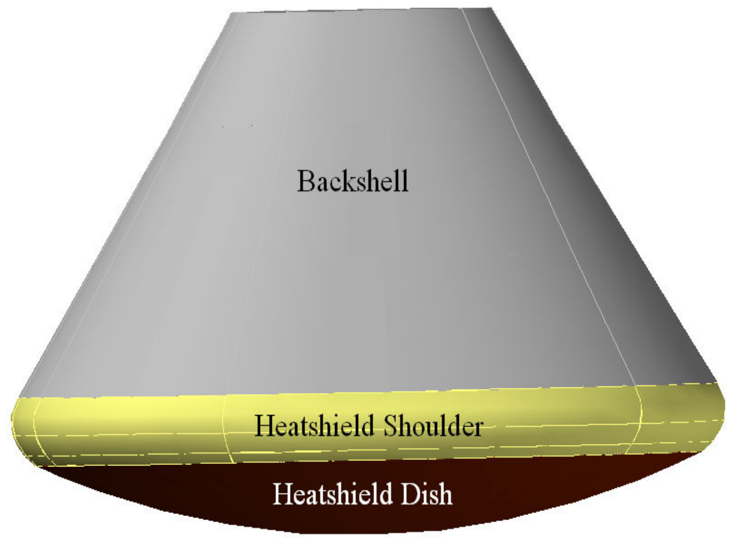


Thermal Math Model

Low Impact Docking System (LIDS) TMM

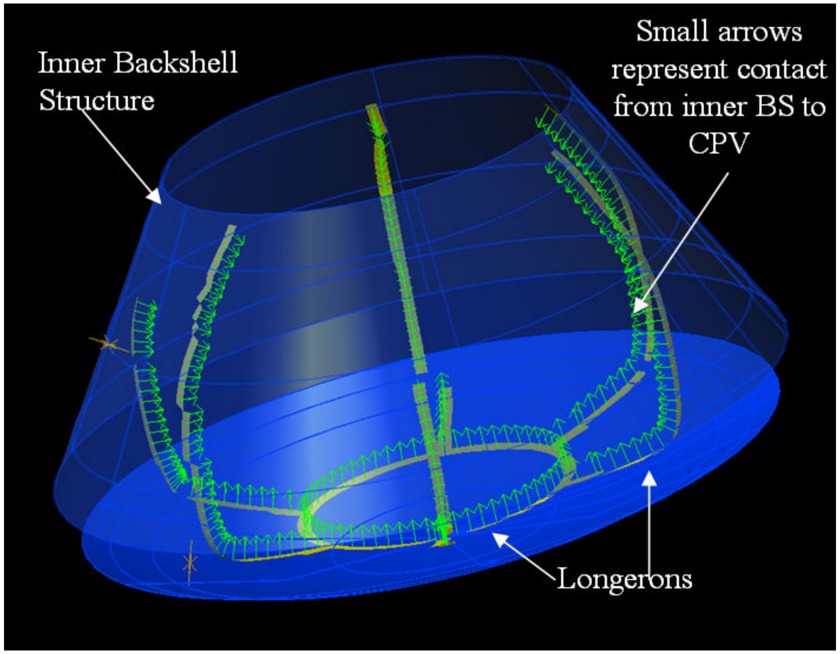


Thermal Protection System (TPS) TMM

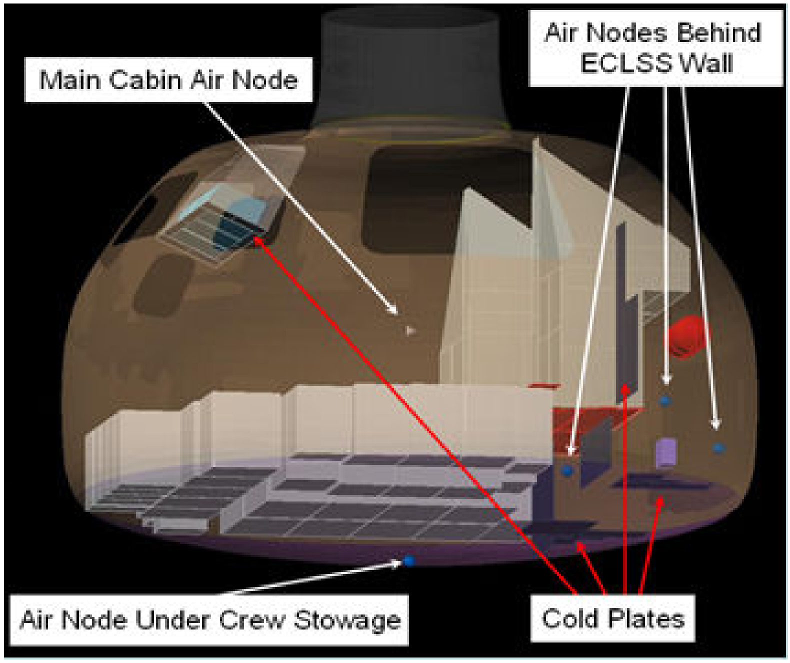


Thermal Math Model

Assumed longeron structural support

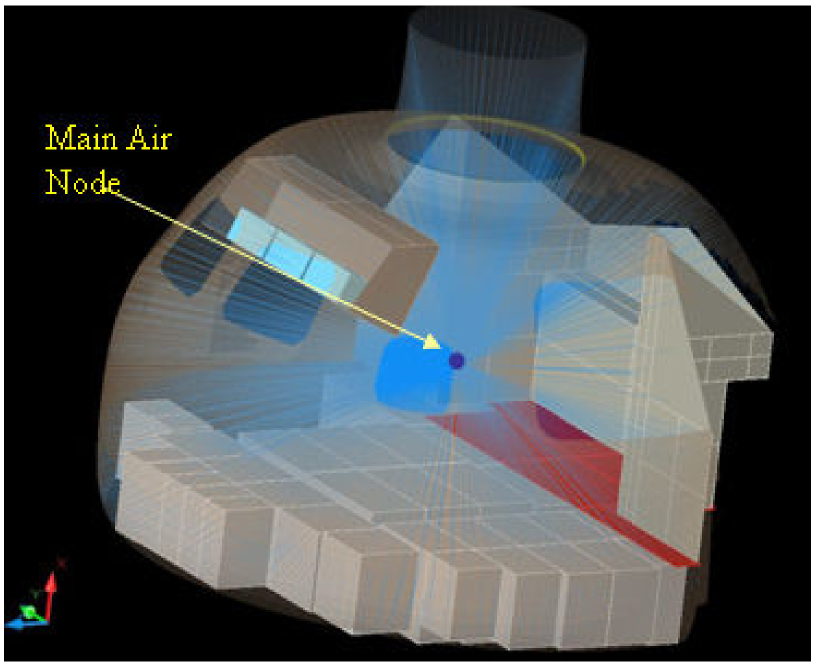


Location of air nodes and cold plates

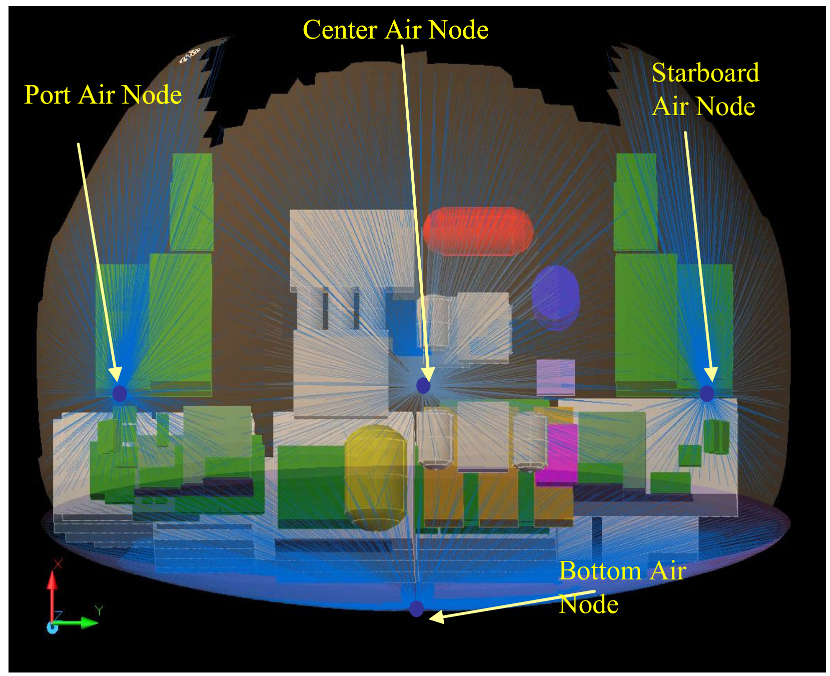


Thermal Math Model

Main air node connections to CPV wall and system surfaces



Port, starboard, center, and under crew stowage air node connections



Analysis

- Make-up energy is the required energy applied to specific locations within the CPV to maintain the inner wall temperature above the 61.5°F (16.4°C) dew point
- Make-up energy differs from heater power in that heater zoning is not taken into consideration
- Specialized SINDA code was written and incorporated into the TMM to calculate the make-up energy

Analysis

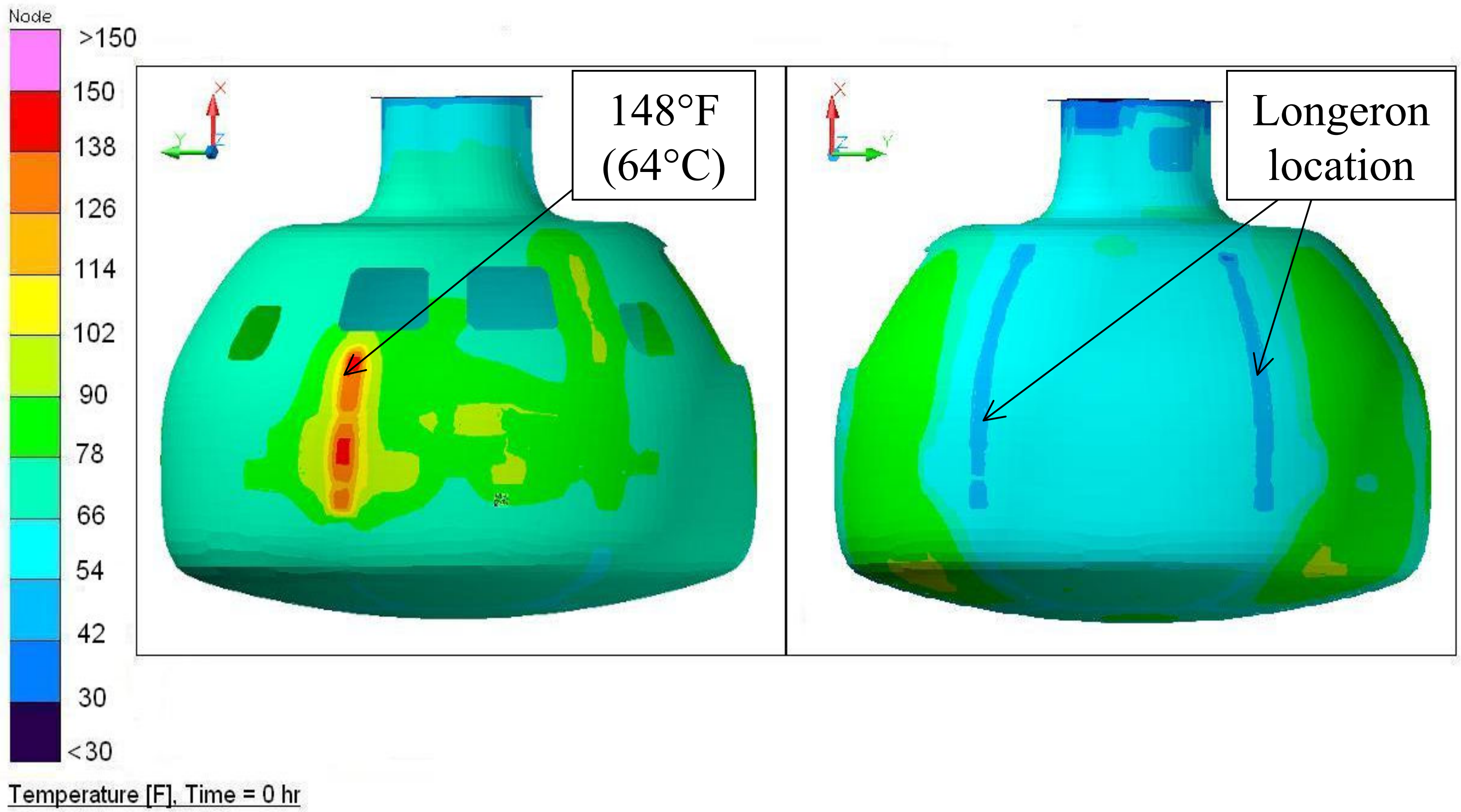
- An initial steady state solution is made with unconstrained inner walls (using SINDA diffusion nodes) to calculate CPV temperature distribution
- Each node with a temperature below the threshold of 61.5°F (16.4°C) is identified
- These identified nodes are redefined as heater nodes set at a boundary of 61.5°F (16.4°C) while the remaining nodes remain unconstrained
- A final steady state solution is made including heater nodes to determine the make-up energy

Analysis

Case	Orientation	Natural Environments
Lunar transit, broad side to sun	The main axis of the vehicle is perpendicular to the sun vector. Half of the vehicle receives full, constant sun, the other half views deep space.	Hot solar flux. No albedo or Outgoing Longwave Radiation (OLR).
Lunar transit, aft to sun	The SM main engine faces the sun. Thus the entire CM is continuously shaded and sees deep space.	Cold solar flux. No albedo or OLR.
Low Lunar Orbit (LLO), nose to sun, Beta (β)=90°, 90 km altitude above lunar surface	The hatch/docking mechanism on the CM faces the sun full on.	Hot solar flux, albedo, and OLR.
LLO, aft to sun, β=90°, 90 km altitude above lunar surface	The SM main engine faces the sun. Thus the entire CM is continuously shaded and sees deep space. There is minimal albedo and OLR heating.	Hot solar flux, albedo, and OLR.

Results

- Steady State Temperature Results, Lunar Transit, Broadside to Sun, Minimum Inner Wall Temperature ≥ 61.5°F (16.4° C)



Results

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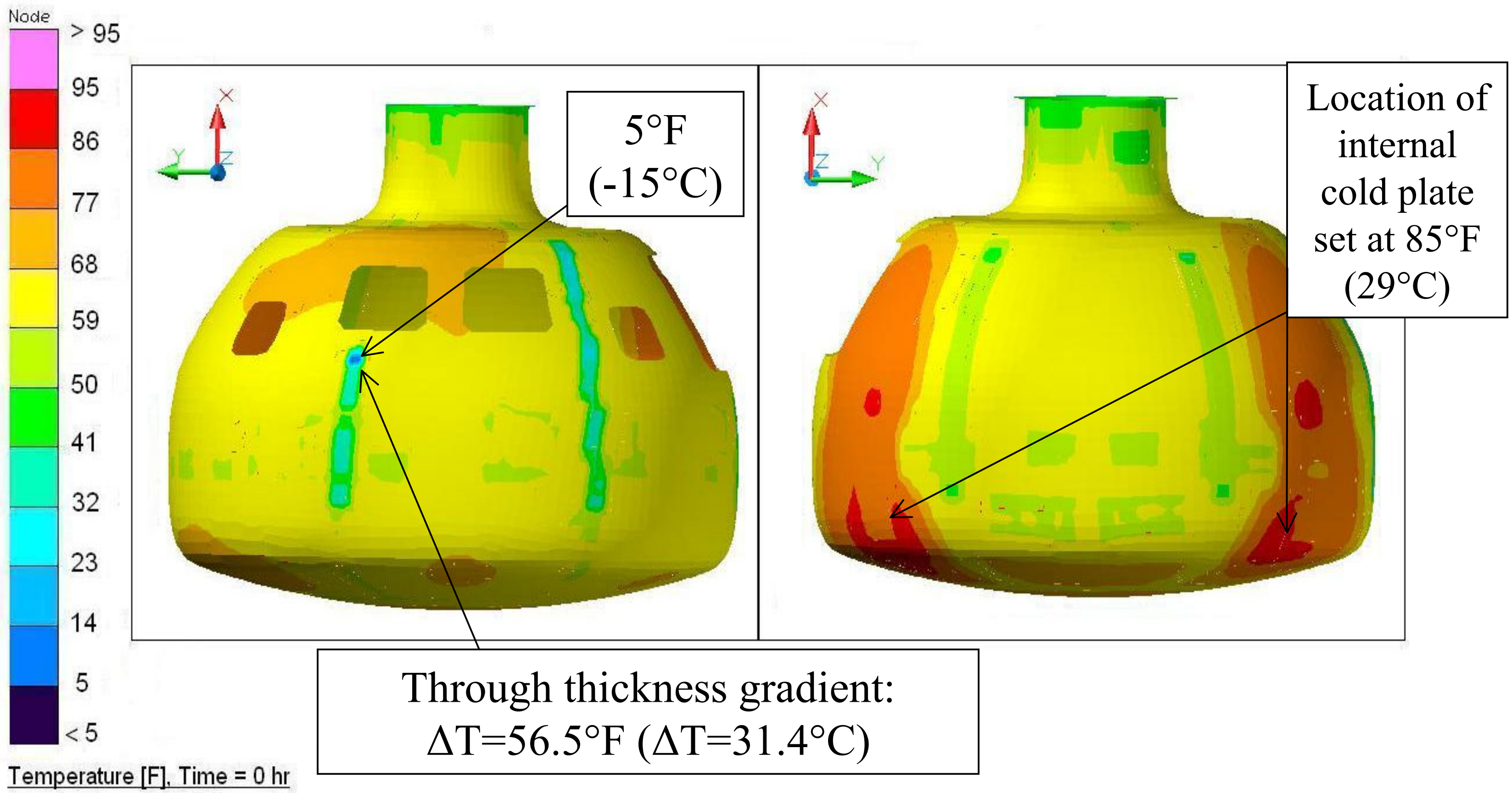
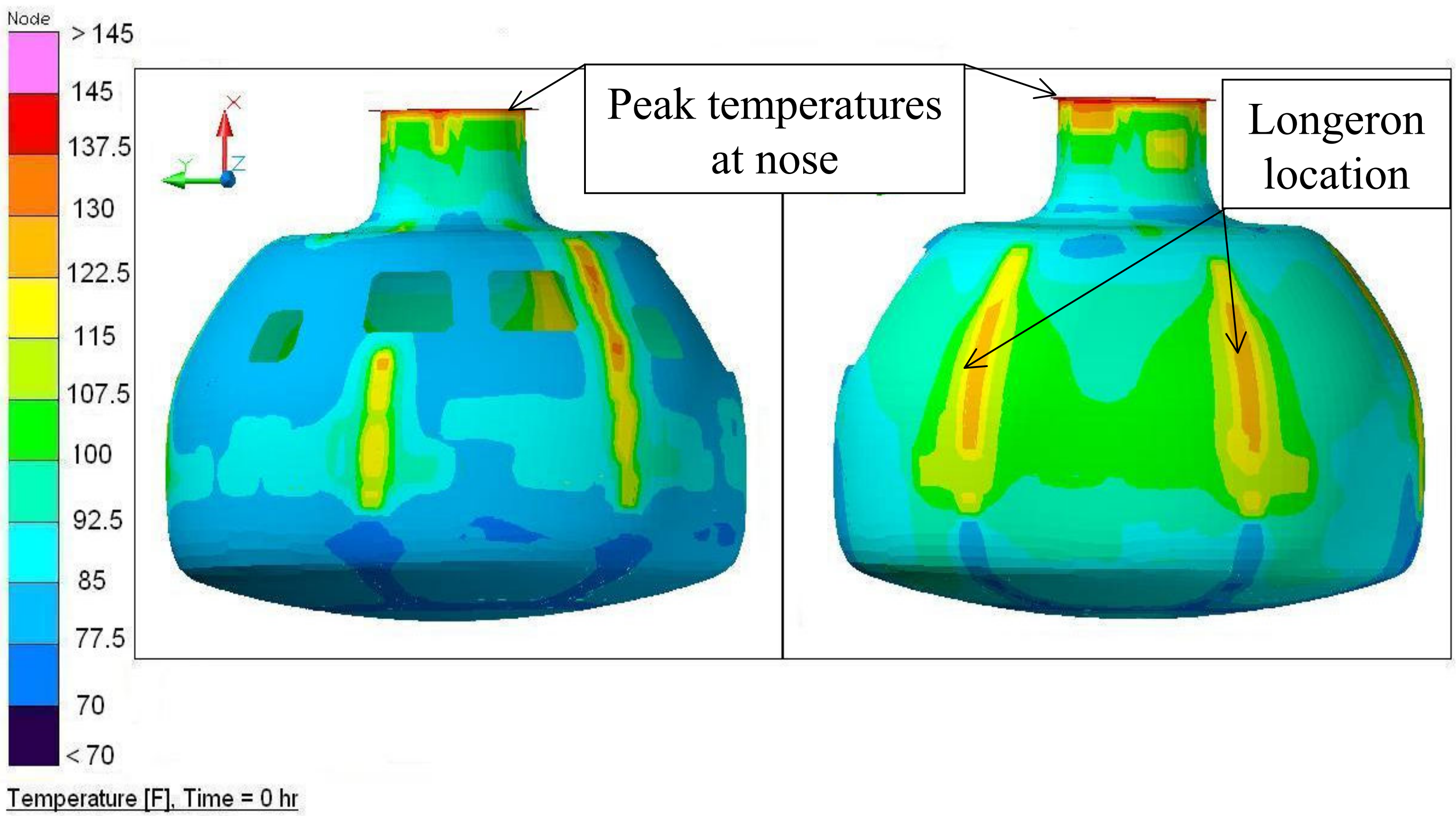


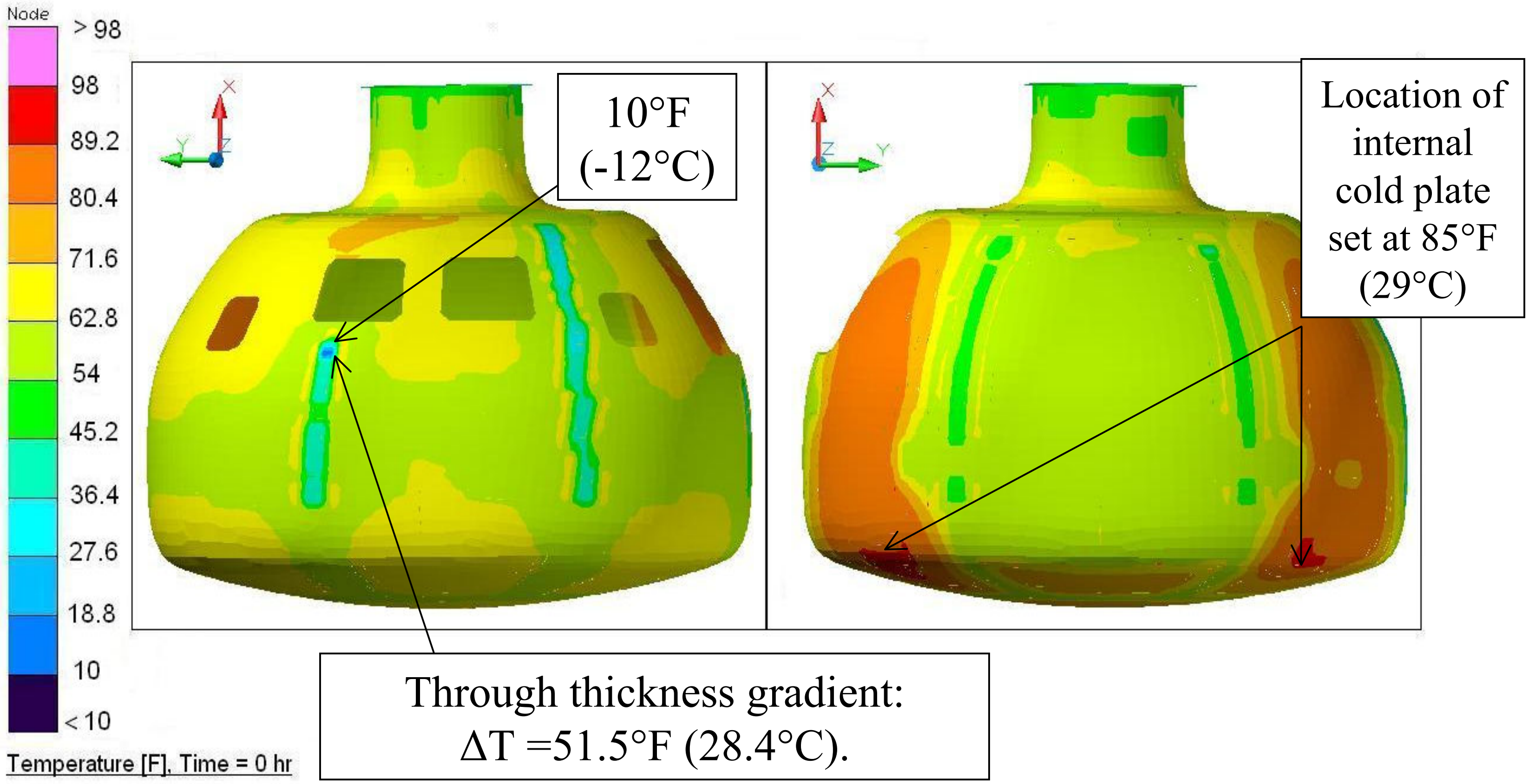
Results

- Steady State Temperature Results, Low Lunar Orbit, Nose to Sun, β=90°, Minimum Inner Wall Temperature ≥ 61.5°F (16.4°C)



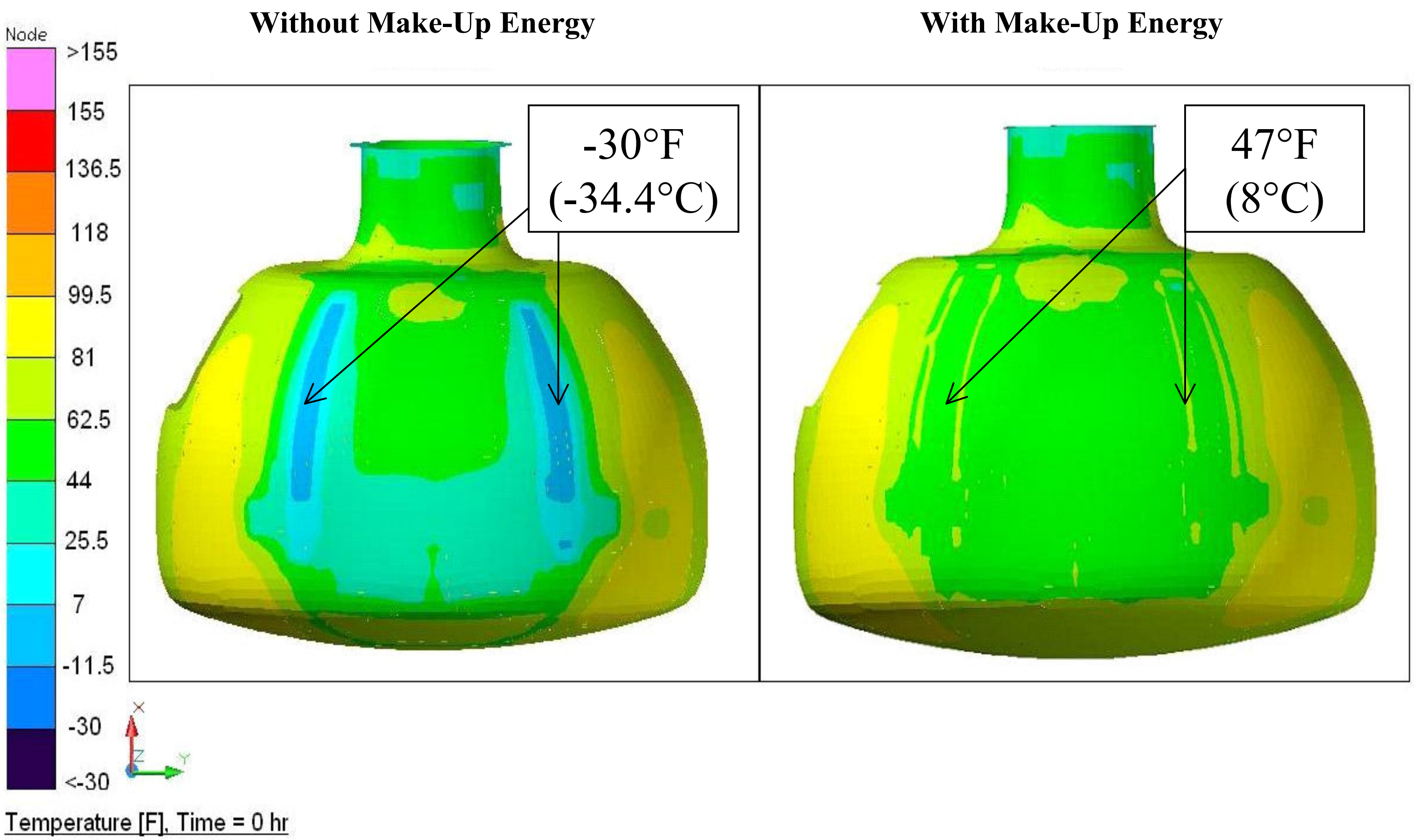
Results

- Steady State Temperature Results, Low Lunar Orbit, Aft to Sun, β=90°, Minimum Inner Wall Temperature ≥ 61.5°F (16.4° C)



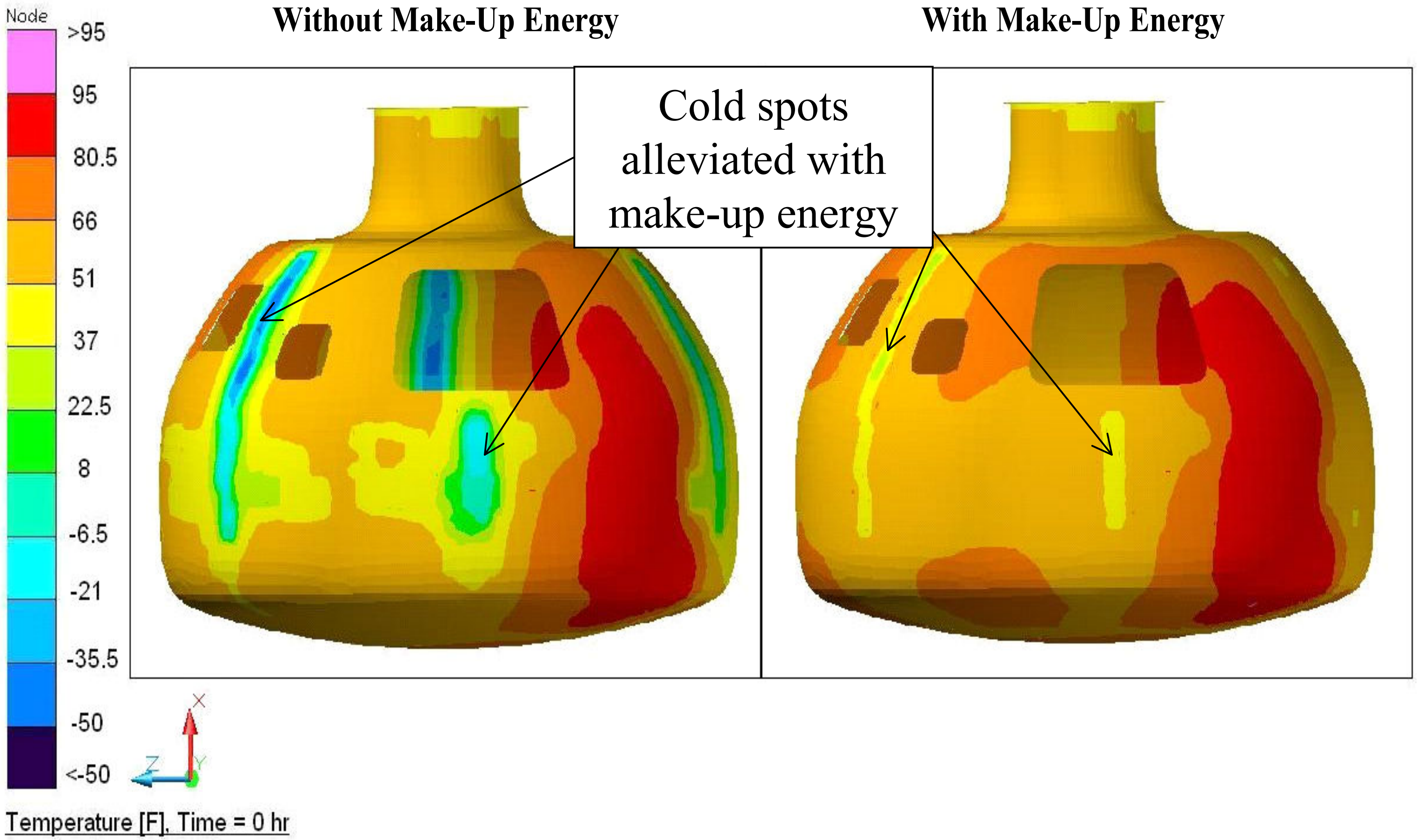
Results

- Effect of Make-Up Energy, Steady State Temperature Results, Lunar Transit, Broadside to Sun, β=90°, Minimum Inner Wall Temperature ≥ 61.5°F (16.4°C)



Results

- Effect of Make-Up Energy, Steady State Temperature Results, Low Lunar Orbit, Aft to Sun, Minimum Inner Wall Temperature ≥ 61.5°F (16.4°C)



Conclusion

- Qualitative Overview
  - Limited heater zoning data
  - Enables an assessment of observed trends
- CPV requires significantly less make-up energy to hold the inner wall temperature above 61.5°F (16.4°C) compared to aluminum baseline
  - An average 60% decrease
  - LLO nose to sun: 100% decrease (No make-up energy required)
  - Transit broadside to sun: 70% decrease
  - Transit aft to sun, LLO aft to sun: 30-40% decrease

Recommendations

- Temperature gradients indicate possible performance issues from thermomechanical stress
  - Recommend further investigation to quantify thermo mechanical stresses
- Only local make-up energy was considered
  - Recommend a heater zoning study to determine configuration of the required heaters to enable quantitative heat power assessment

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