Effects of Re-entry and Post-Landing Heating on the Orion Crew Module Cabin Air Temperature

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Topics

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- Environments
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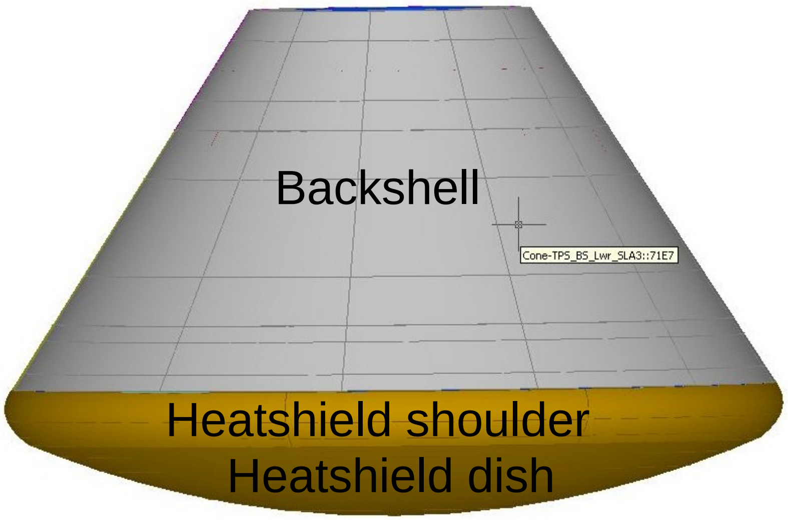
Introduction

- In addition to surviving re-entry, the Orion Crew Module (CM) must also provide a safe haven for the crew if a quick recovery is not possible.
  - The Orion project requires 36 hours of survival capability after a water landing.
- The purpose of this analysis was to determine the cabin air temperature taking into account re-entry heating and soak-back, and the post-landing thermal environment.

Model Development



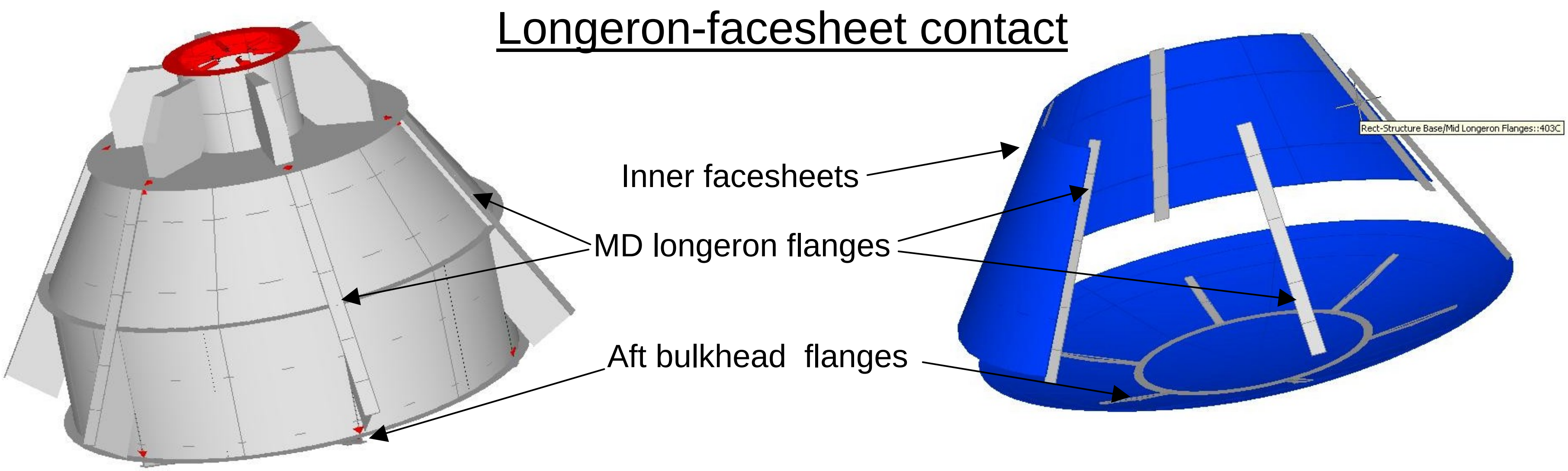
<u>Optical Properties</u>

- Backshell/Heat Shield
  - on-orbit: α/ε=0.3/0.3
  - Re-entry to landing: α/ε=0.9/0.9
- Inner facesheet: (titanium) ε=0.2

<u>TPS Stack-Up</u>

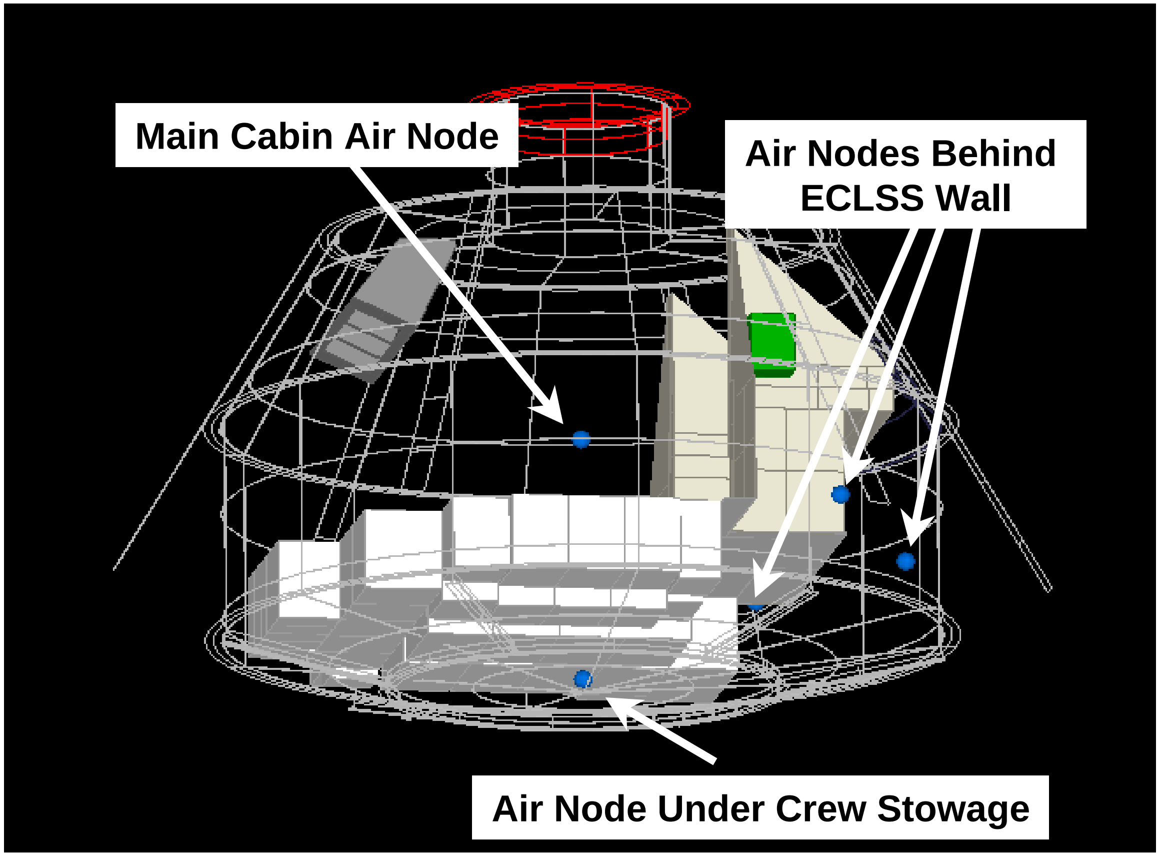
- Backshell (BS)
  - AETB-8
  - Titanium Honeycomb
- Heat Shield (HS) dish
  - Phenolic Impregnated Carbon Ablator (PICA)
  - Titanium Honeycomb
- Heat Shield (HS) shoulder
  - PICA
  - Titanium Plate

Model Development, Continued



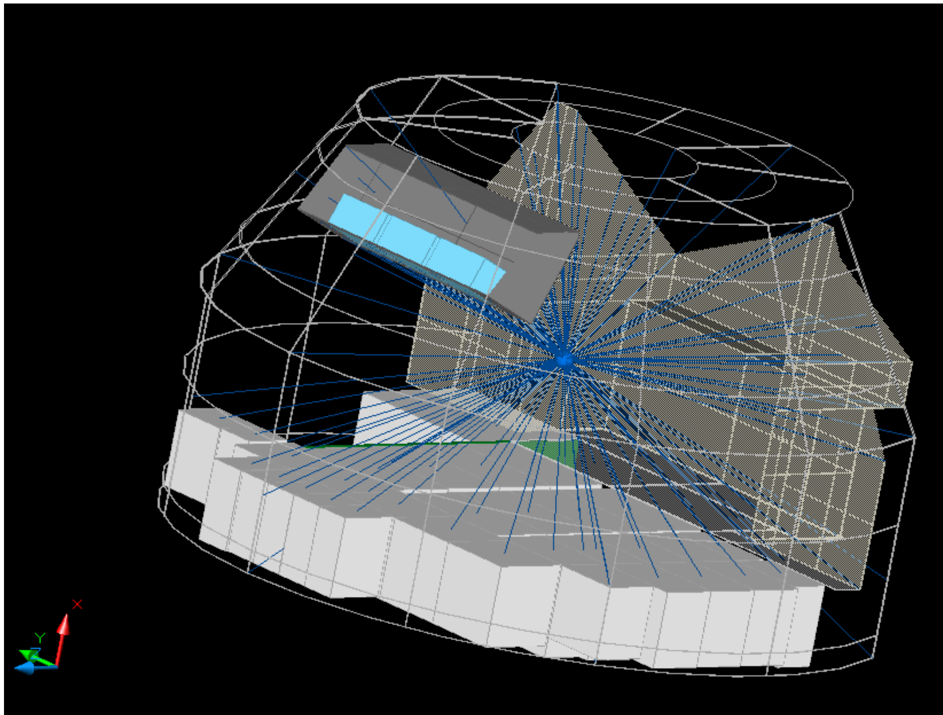
- Contactors were used to connect the longeron-inner facesheets & shoulder-backshell elements.
- Longeron-facesheet & aft bulkhead flanges:
  - G = 52.7 W/K
- Shoulder-backshell (facesheets):
  - G = 0.005 W/K

Model Development, Continued



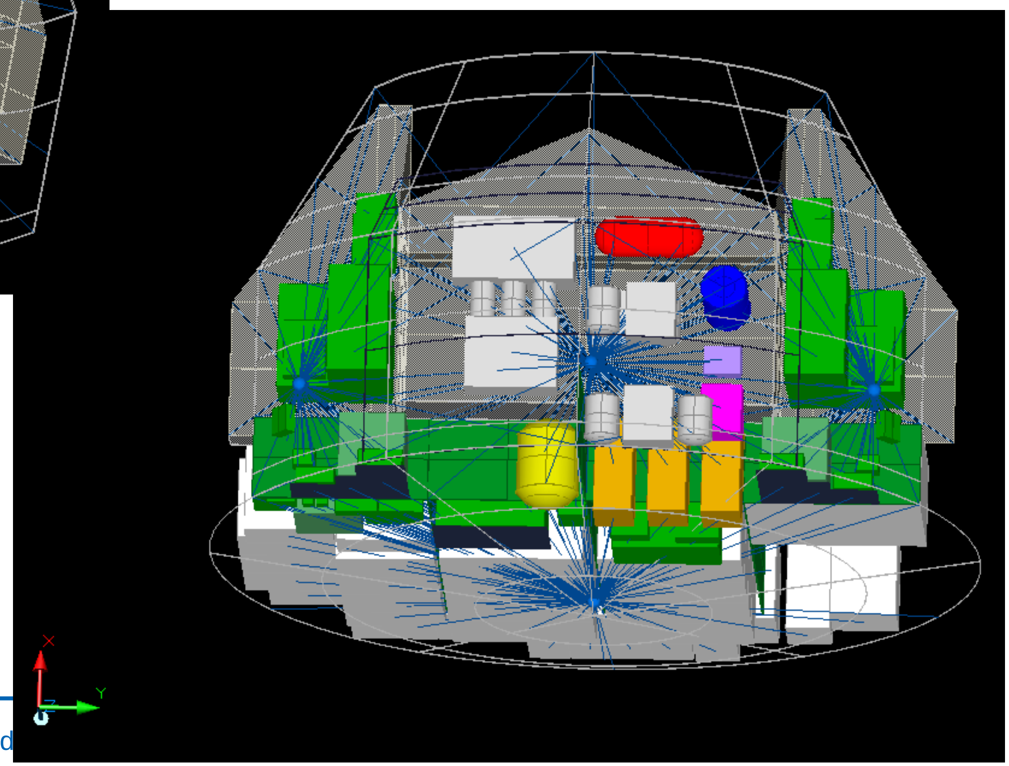
- Pressure Vessel (PV) Air Nodes
  - 5 air nodes inside pressure vessel.
  - No coupling between air nodes.
- Estimated unoccupied volumes:
  - Main: 10.43 m^3
  - Port: 0.55 m^3
  - Stbd: 0.55 m^3
  - Center: 1.2 m^3
  - Under Crew Stowage: 1.46 m^3
- Total PV volume:
  - 20.32 m^3

Model Development, Continued



Air node coupling to PV structure and inner components.

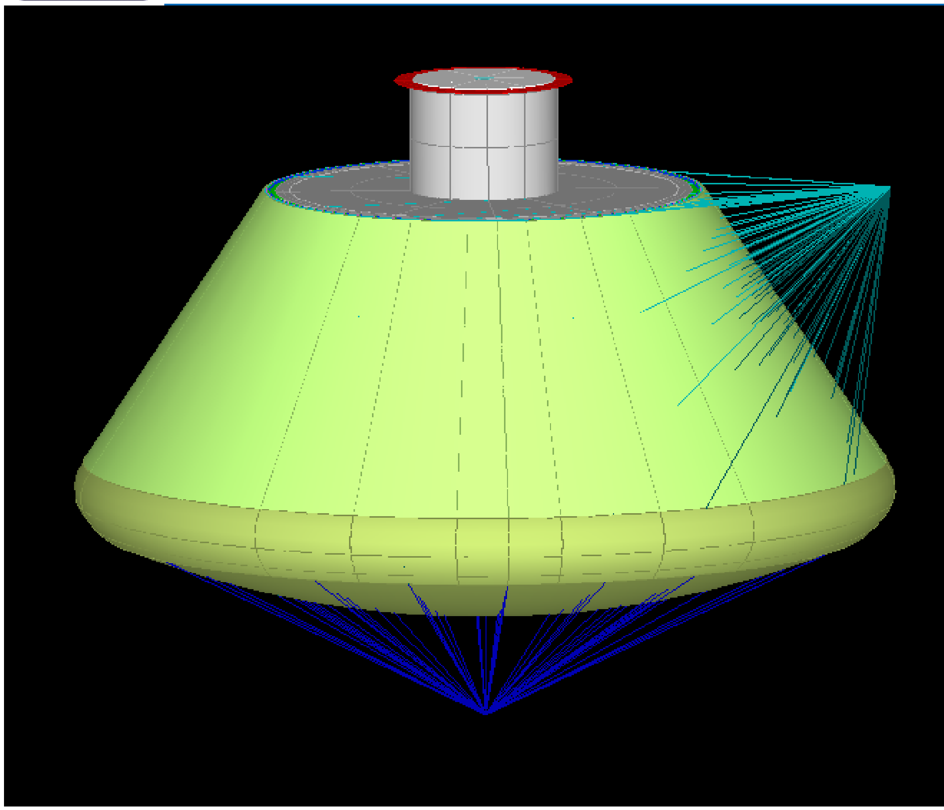
- PV main node connection (left picture)
- Remaining nodes (right picture)
- No direct coupling between nodes.



Power dissipation

- Pre-landing: 2408.5 W
- Post-landing: 1149.3 W

Model Development, Continued



BS & HS descent & landing conductors

- No Fwd Bay cover during descent.
- Analysis does not include convection in the Fwd Bay during descent phase.
- Logic block used to obtain Heat Transfer Coefficients (HTCS) using corresponding correlations.

Descent

Assumptions: Flat plate (BS) /Sphere (HS)

$$\overline{Nu}_{L,BS} = 0.029 * \mathrm{Re}_L^{0.8} * \mathrm{Pr}^{0.43}$$

$$\overline{Nu}_{D,HS} = 2 + \left(0.4 * \mathrm{Re}_D^{0.5} + 0.06 * \mathrm{Re}_D^{2/3}\right)\mathrm{Pr}^{0.4}$$

Post-landing

$$\overline{Nu}_{L,BS} = 0.68 + \left(0.67\left(Ra_L \Psi\right)^{1/4}\right)\left(1 + 1.6 * 10^{-8} Ra_L \Psi\right)^{1/12}$$

$$\Psi = \left[1 + \left(\frac{0.492}{\mathrm{Pr}}\right)^{9/16}\right]^{-16/9}$$

$$\overline{Nu}_{D,HS} = 2 + \frac{0.589 Ra_D^{1/4}}{\left[1 + \left(\frac{0.469}{\mathrm{Pr}}\right)^{9/16}\right]^{4/9}}$$

Analysis Cases

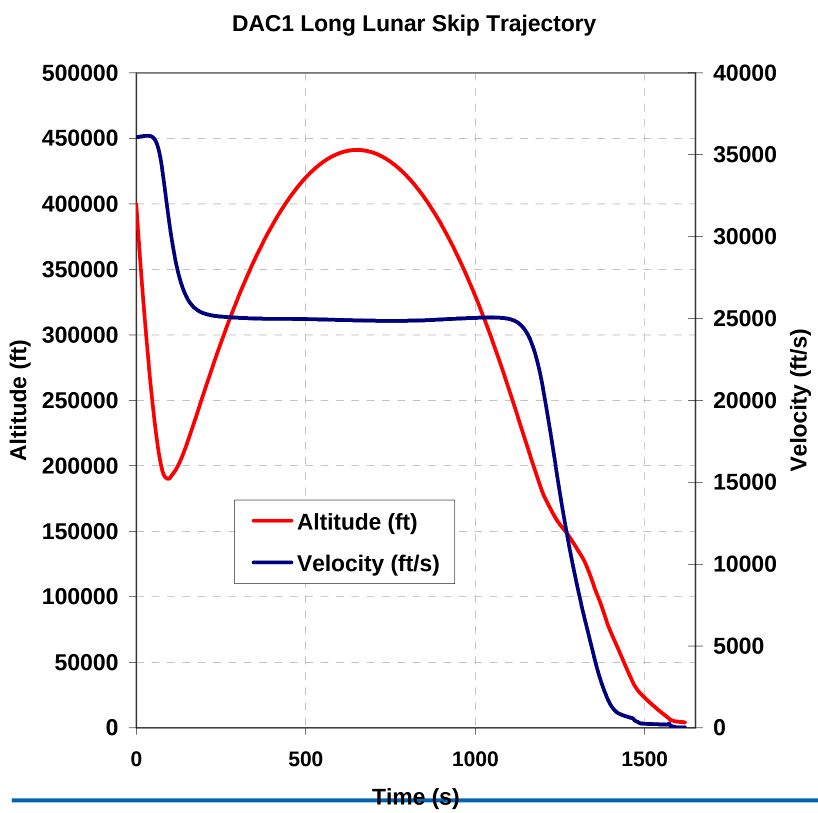
5 phase analysis

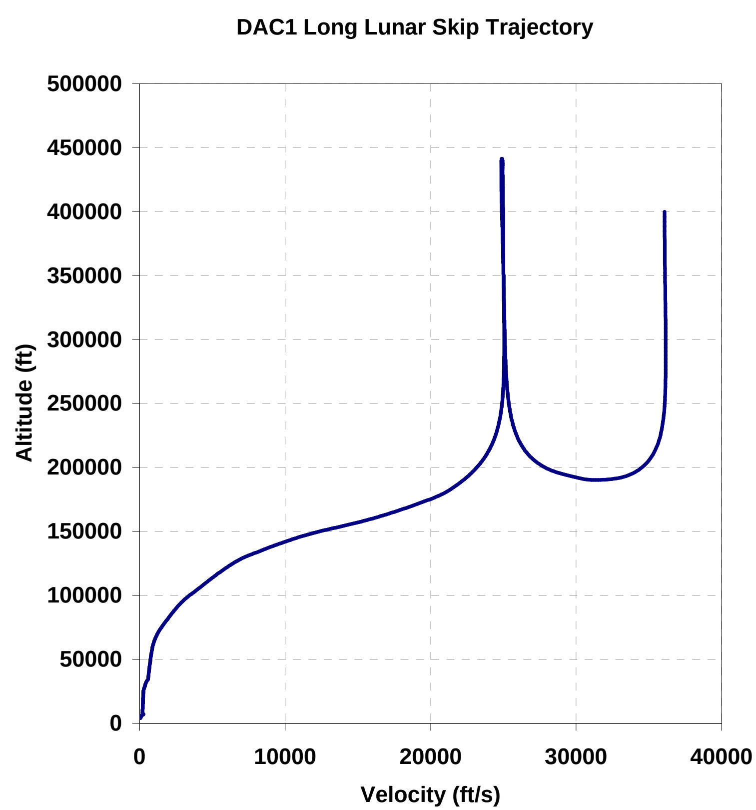
- 1. Lunar Transit: Steady state solution
  - Service Module attached, aft sun attitude
- 2. Pre-entry orbit: 0-1884 sec.
  - 120 km LEO with HS on the velocity vector
- 3. Entry: 1884-3284 sec.
  - Heating stopped after 1400 sec
  - Main air node changed to diffusion node.
- 4. Descent: 3284-3667 sec.
  - Convective cooling applied to HS and BS.
  - FWD Bay cover removed.
  - DSNE used for Solar flux and Sky temps
- 5. Post-landing: 3667-14784 sec (3hrs post landing)
  - Natural convection used.

- Parametric run of 20 cases done with different environment temperatures (Air and Sea temperatures)

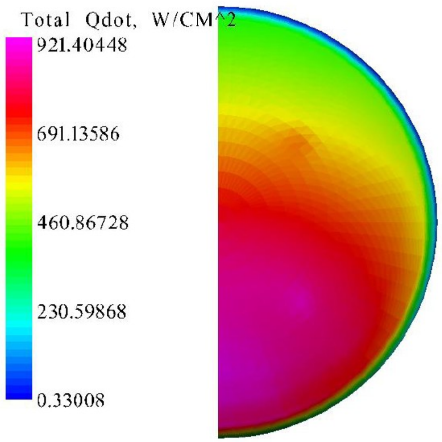
Analysis Cases, Continued

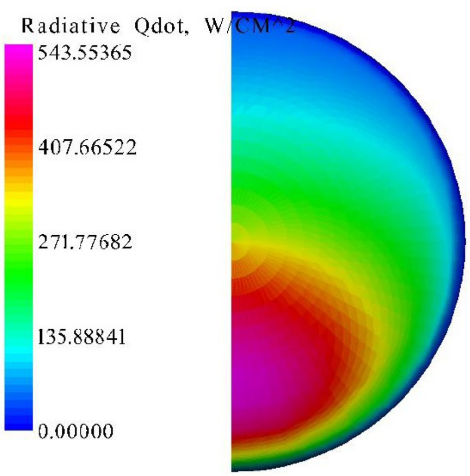
- Reentry phase was based on a long lunar return, skip entry trajectory
- Highest total heat load of lunar and ISS cases.
- Nominal aerothermal heating used – includes a 1.1 factor for trajectory dispersion



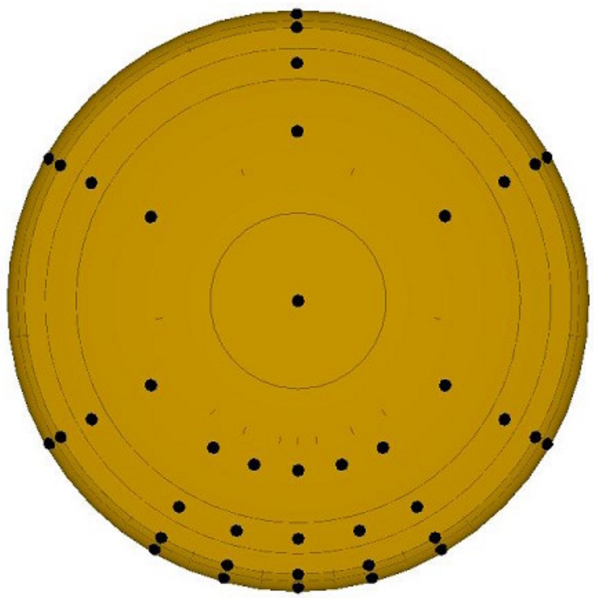


Analysis Cases, Continued

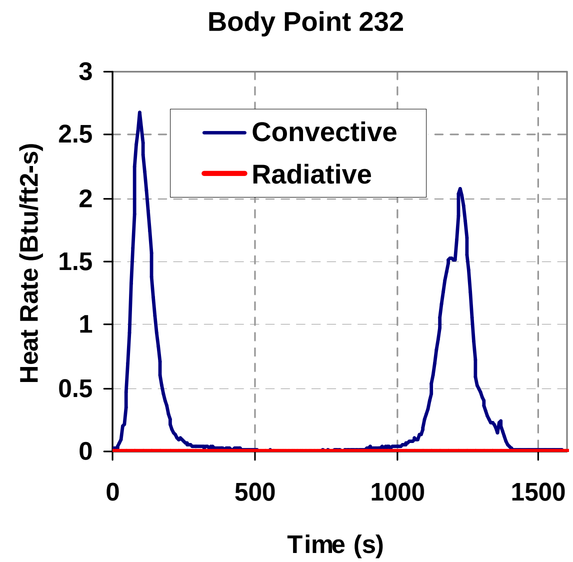


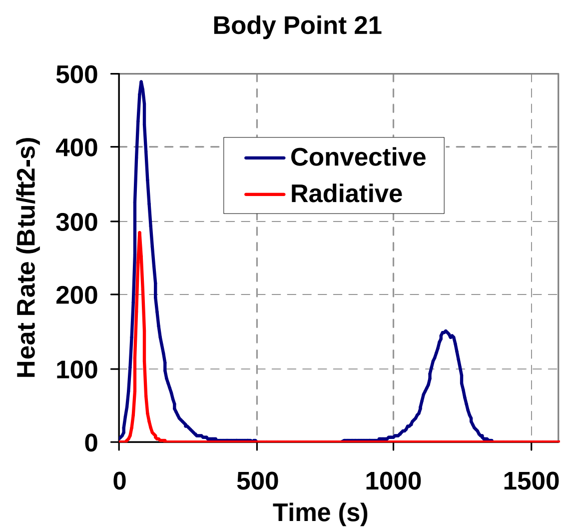


- 52 body points chosen based on heating rate distribution



- Heating varies significantly over the heatshield surface





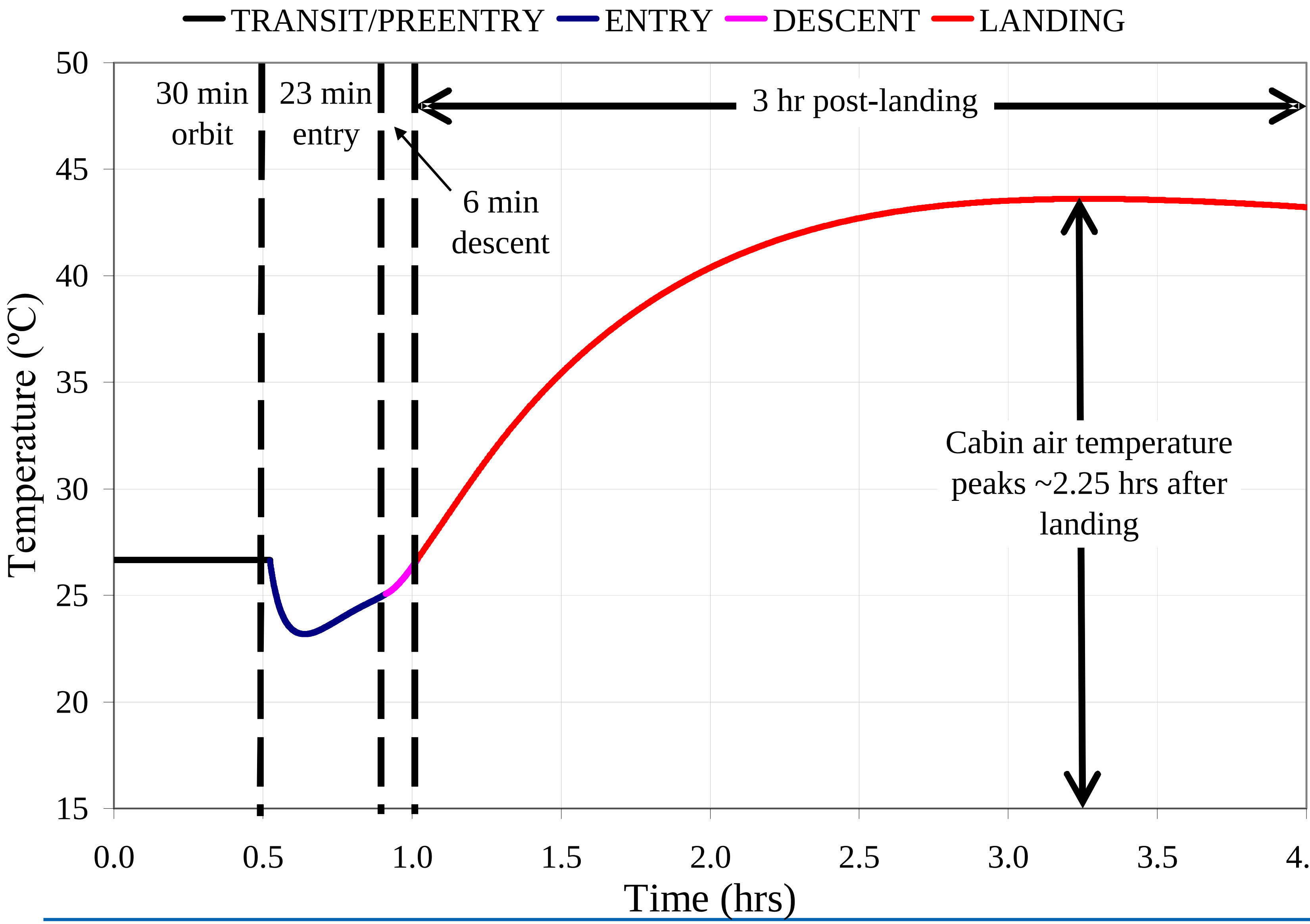
Cabin Air Temperature Results

- Results showed that the cabin air temperature was not sensitive to the environment temperatures analyzed (sea and air temperatures)

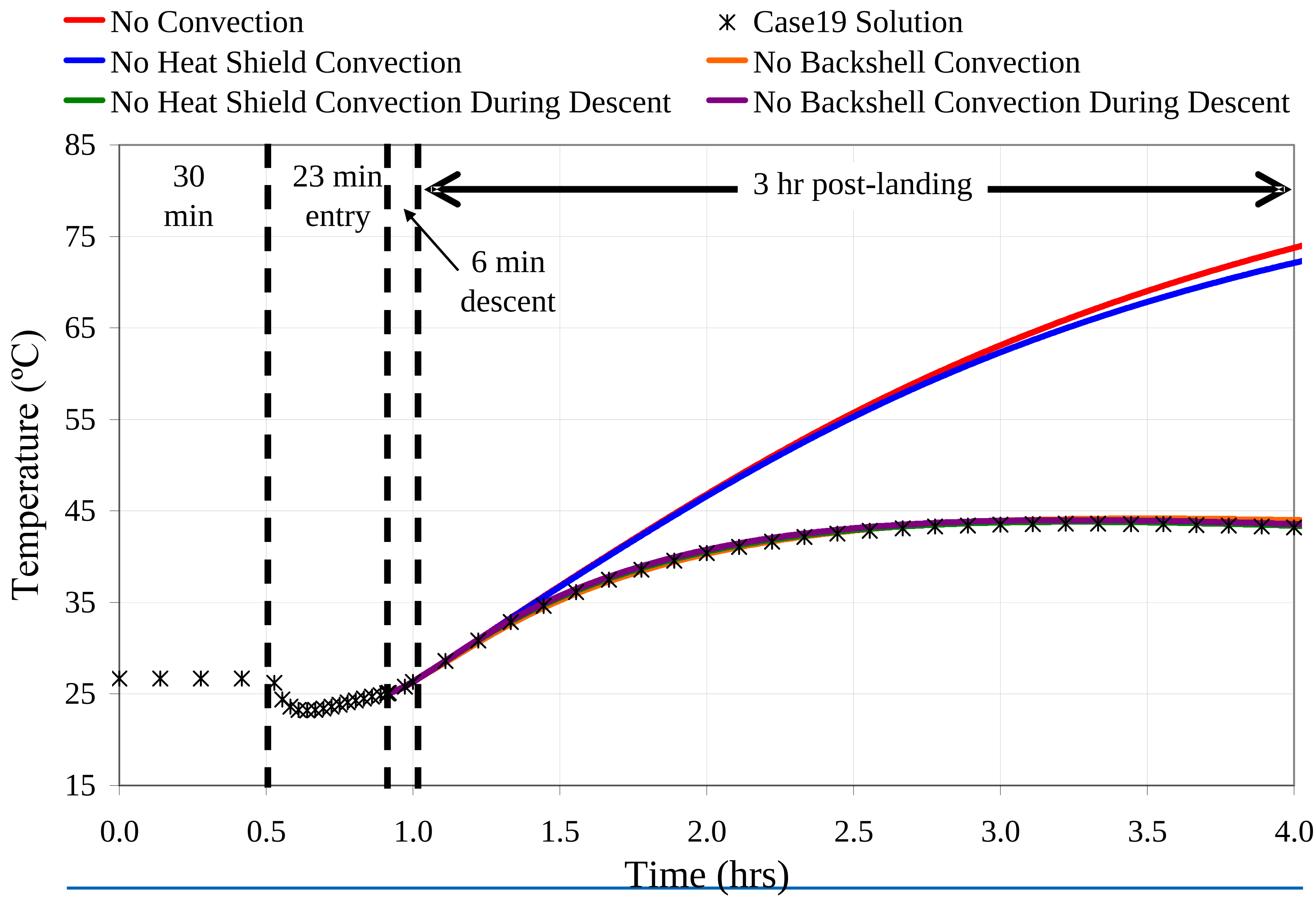
Cabin Main Air Node Temperatures

		Air Temperature (° C)			
		26.7	29.4	32.2	35.0
Sea Temperature (° C)	21.1	42.2	42.8	42.8	43.3
	23.9	42.2	42.8	43.3	43.3
	26.7	42.2	42.8	43.3	43.3
	29.4	42.2	42.8	43.3	43.3
	32.2	42.2	42.8	43.3	43.9

Cabin Air Temp Results
Air Temp = 35 °C, Water Temp = 32.2 °C



Effect of Heat Transfer Coefficient on Cabin Air Temperature



Conclusions

- The main cabin node was not sensitive to the air and sea temperature ranges used as environmental boundaries for convective heat transfer.
- For all cases analyzed, the cabin air temperature reached approximately 43.9 °C within 2.5 hours of landing.
- Convective heat transfer from the backshell during descent and post-land and from the heatshield during the descent has no significant effect on the cabin air temperature
- The heat transfer from the heatshield to the water is critical in removing thermal energy that might otherwise soak back into the vehicle's interior.