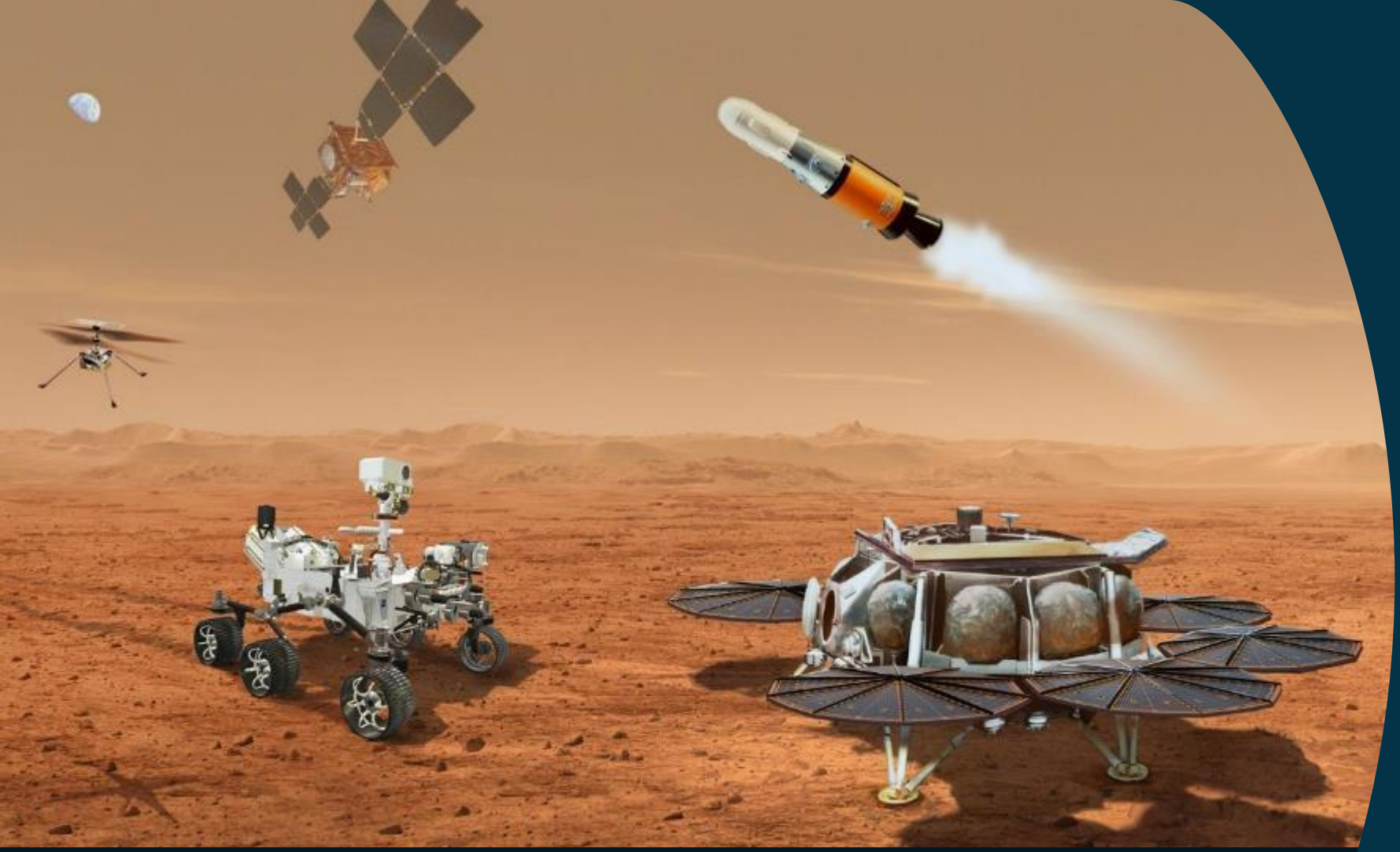

NASA/ESA
MARS SAMPLE RETURN

SAMPLE RETRIEVAL LANDER

Mars Sample Retrieval Lander Thermal Protection System Design

Hannah Alpert
Josh Monk
Milad Mahzari
Suman Muppidi
NASA Ames Research Center

IPPW 2026

Background

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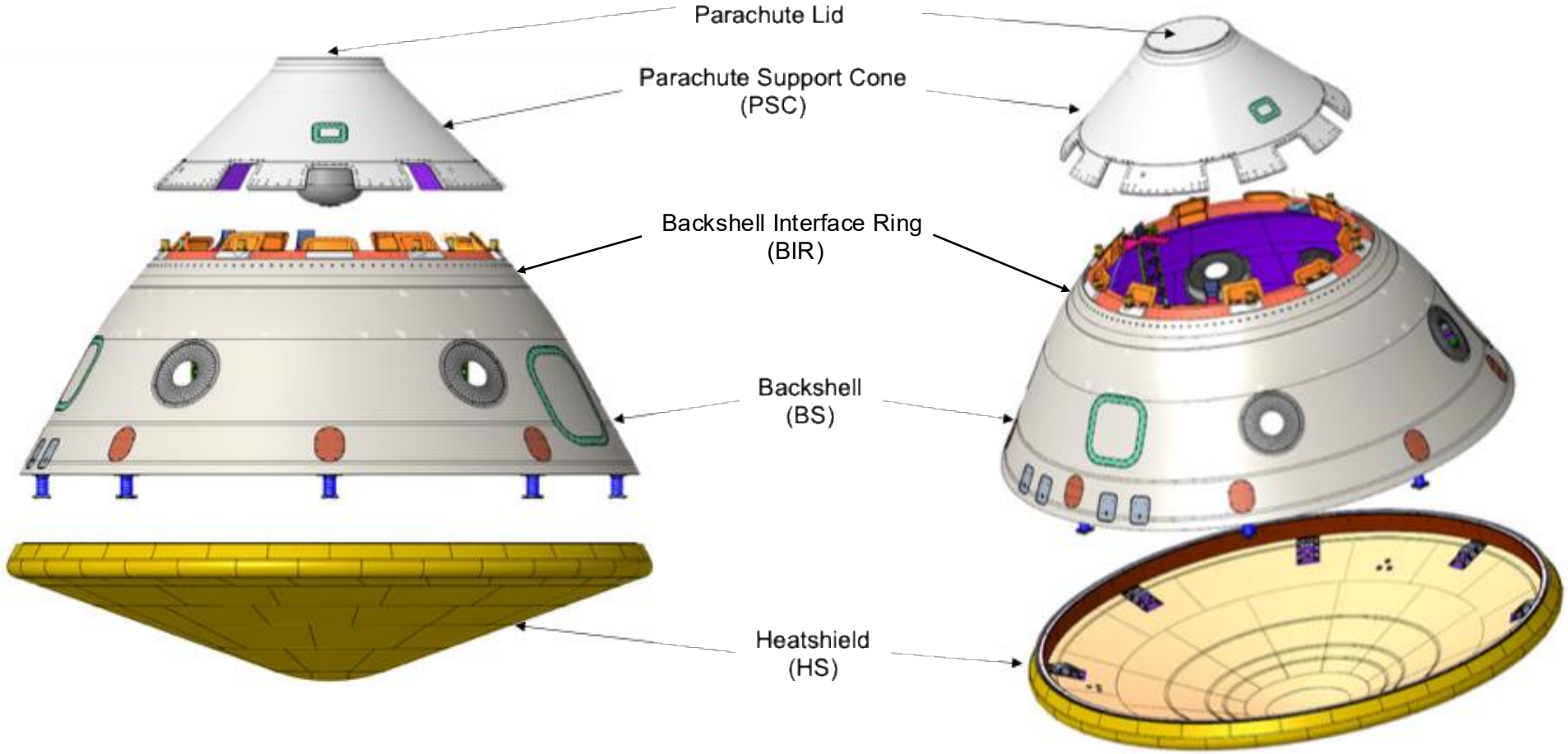
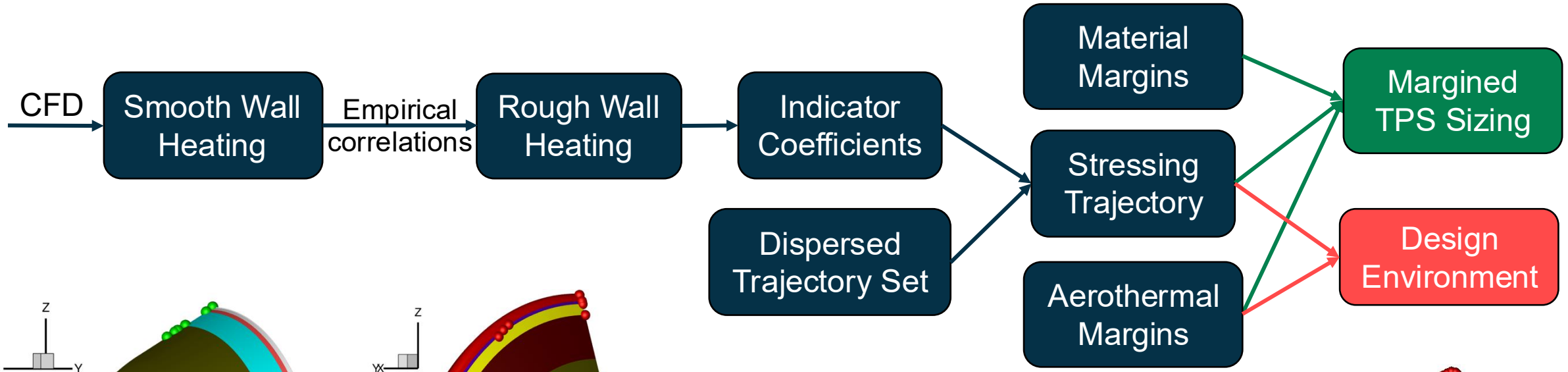
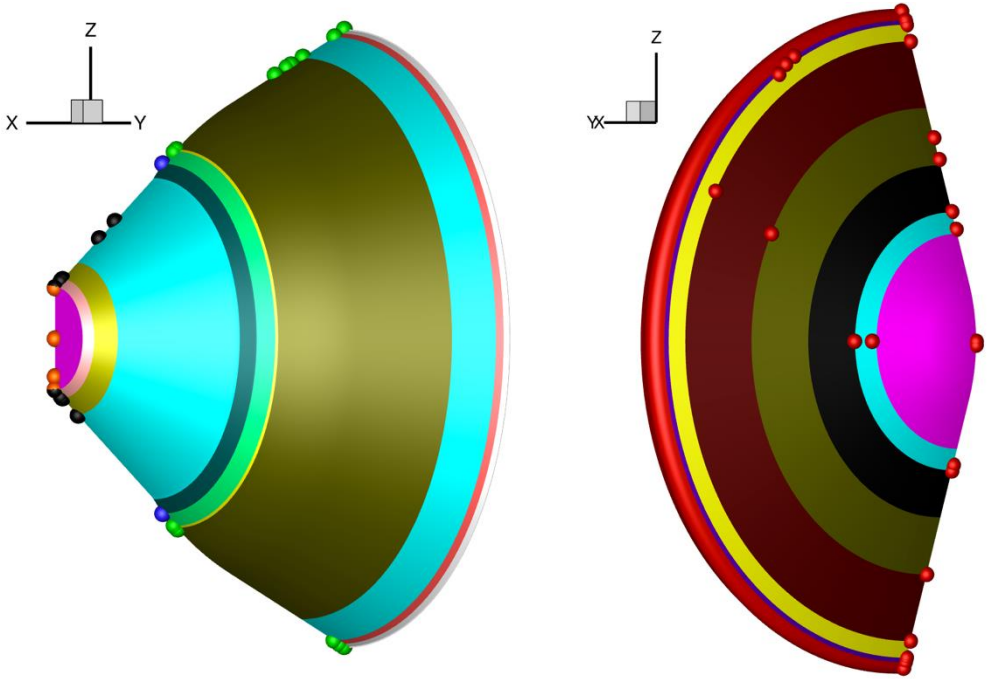
- Mars Sample Return (MSR) Sample Retrieval Lander (SRL) was slated to launch in 2031
- Latest mission architecture included 4.72-m diameter entry capsule entering at 8 km/s

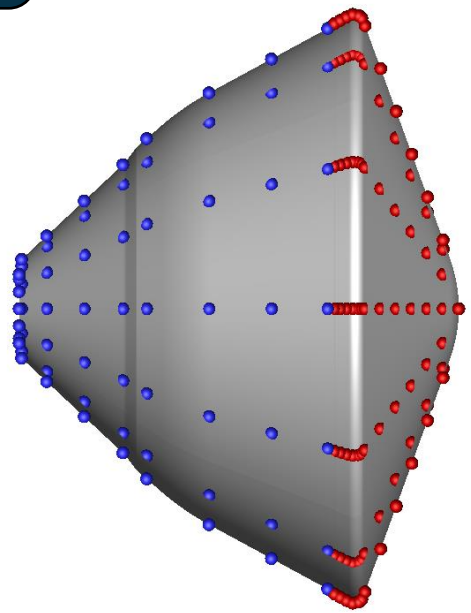


Aeroshell Component	TPS Material
Heatshield	PICA-D
Backshell	SLA-561V
Backshell Interface Ring	Acusil-II
Parachute Support Cone	Acusil-II
Parachute Lid	Acusil-II

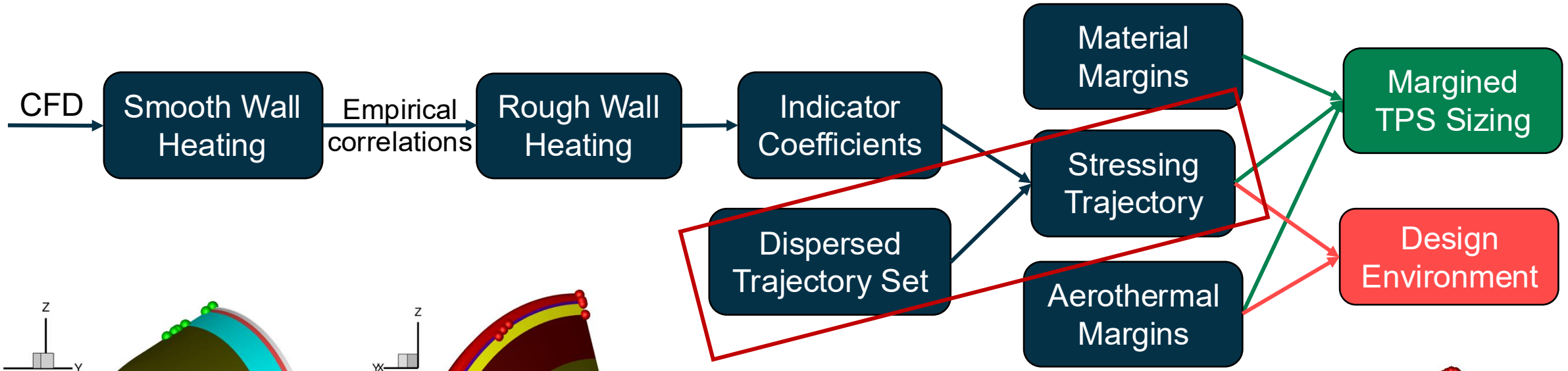
Design Environment and TPS Sizing

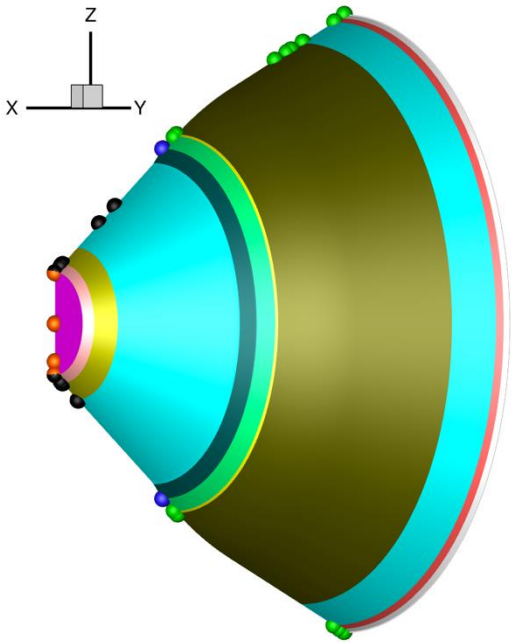


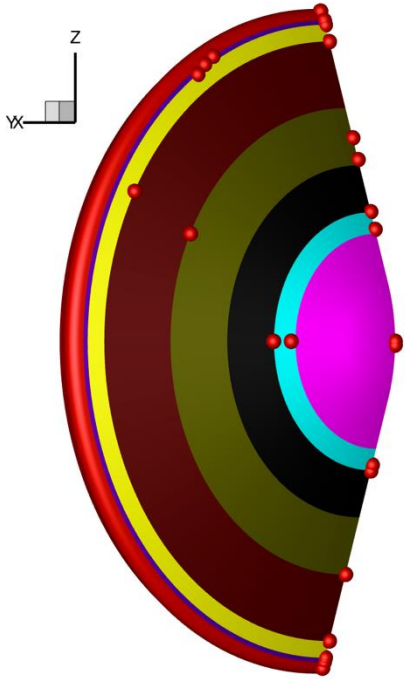


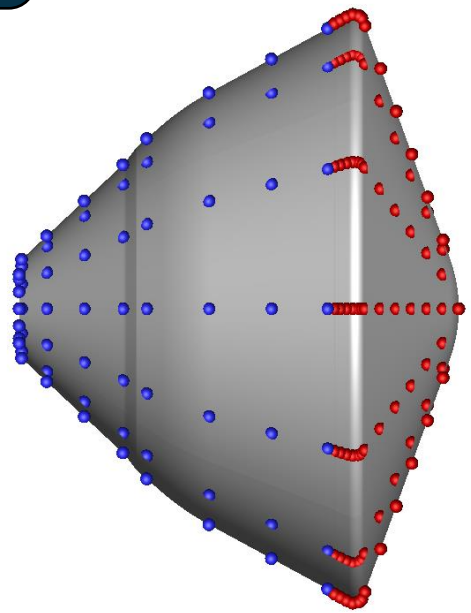


Design Environment and TPS Sizing









Identifying Stressing Trajectories

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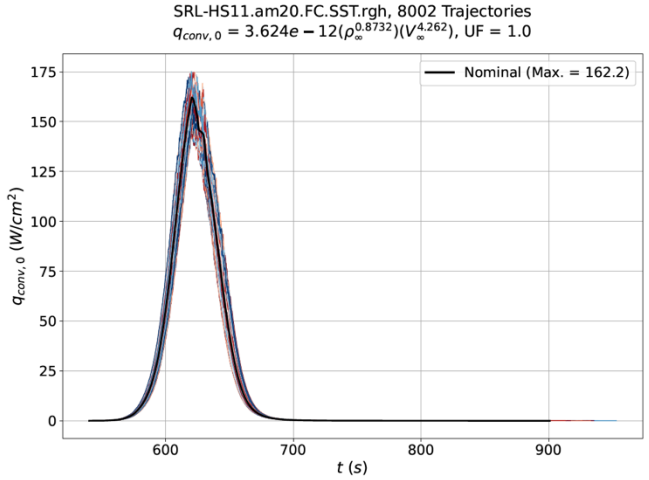
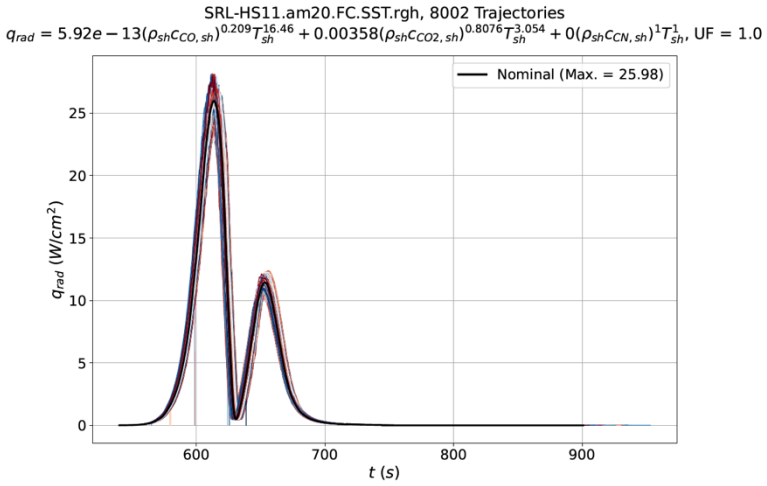
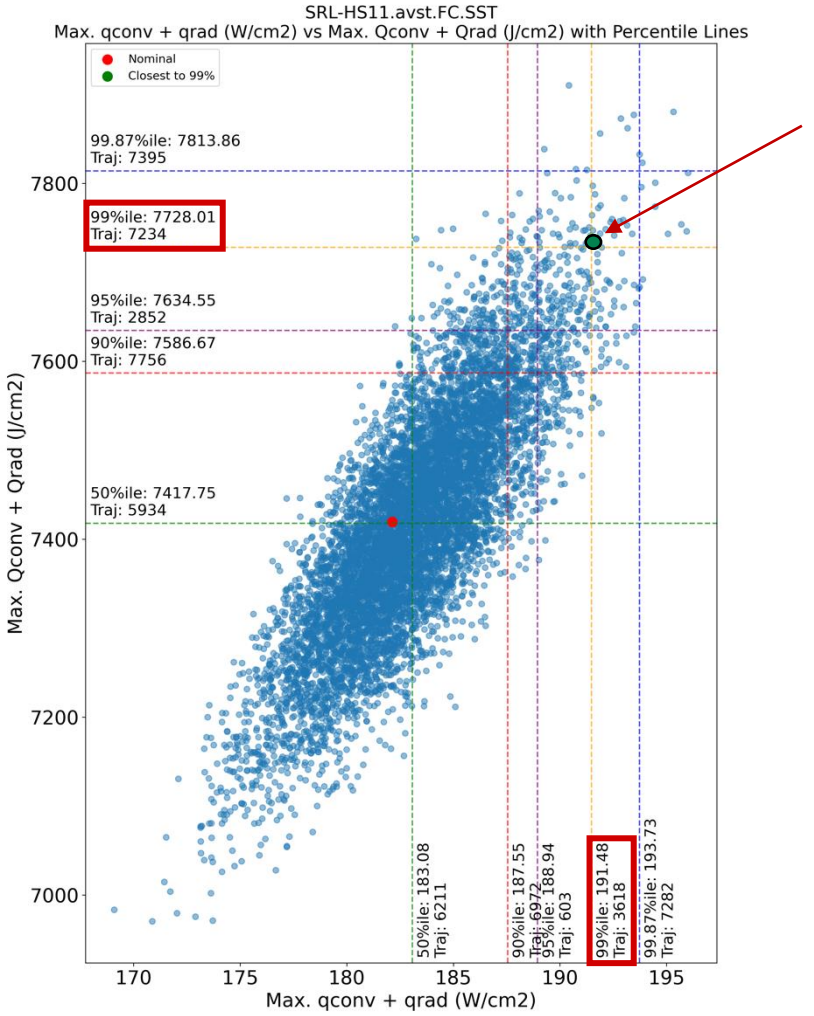
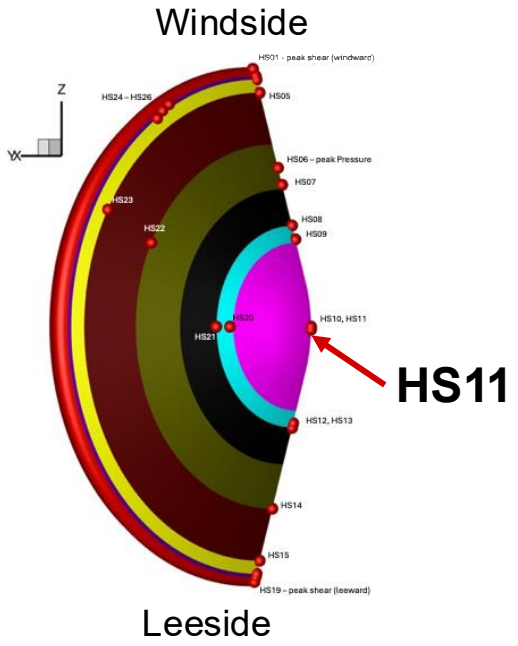
- To identify the design environments for TPS sizing, we chose the trajectory that is closest to both 99% heat flux and 99% heat load



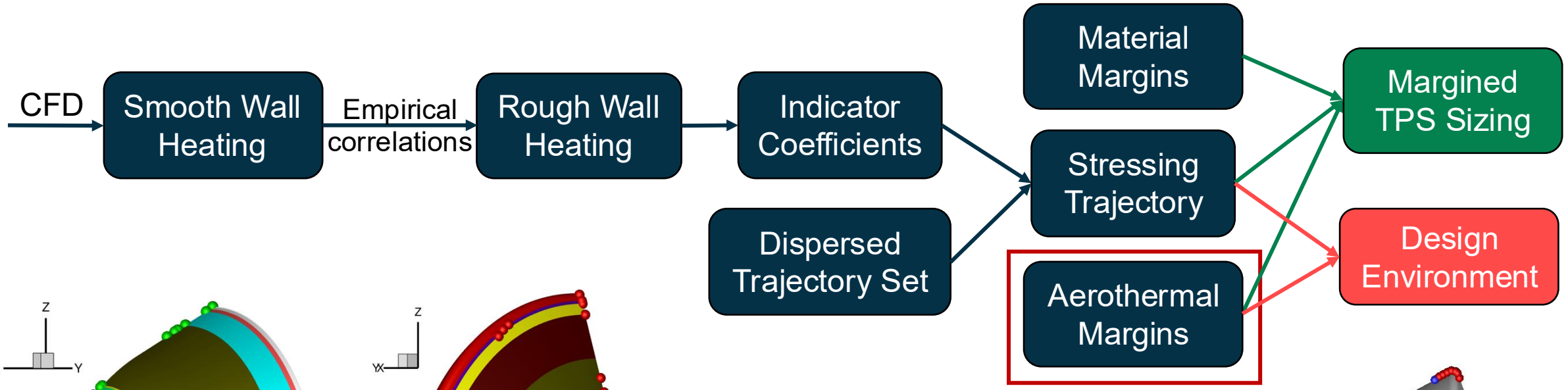


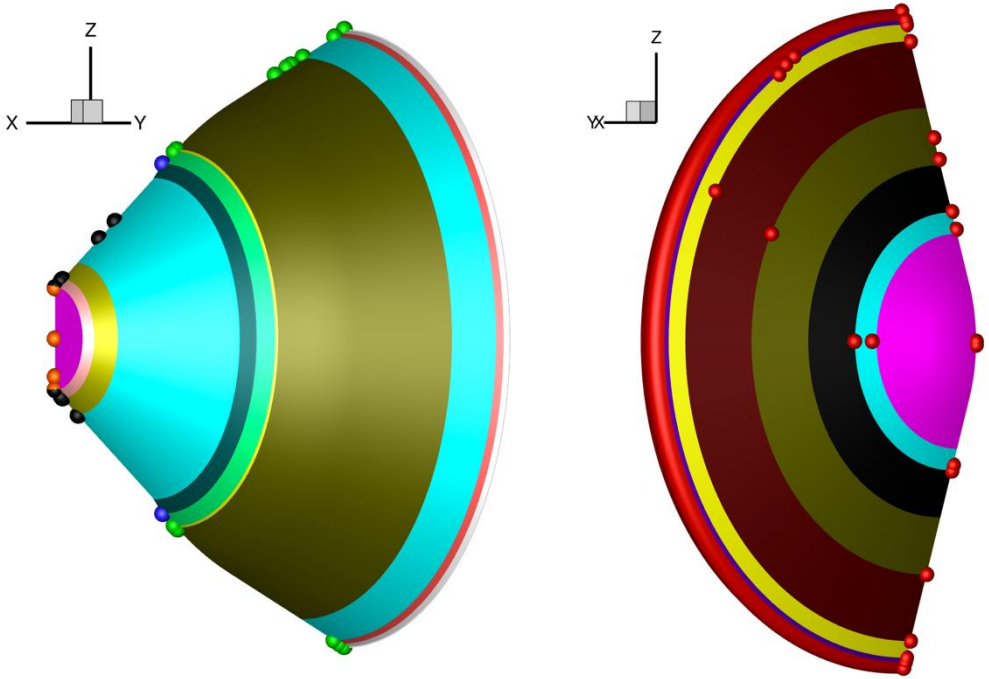


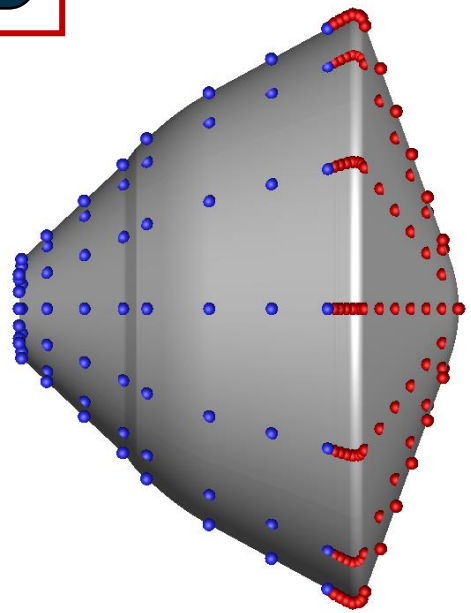


- Fixed AoA (-20°)
- Turbulent (SST)
- Rough wall
- Unmargined

Design Environment and TPS Sizing







Aerothermal Margins

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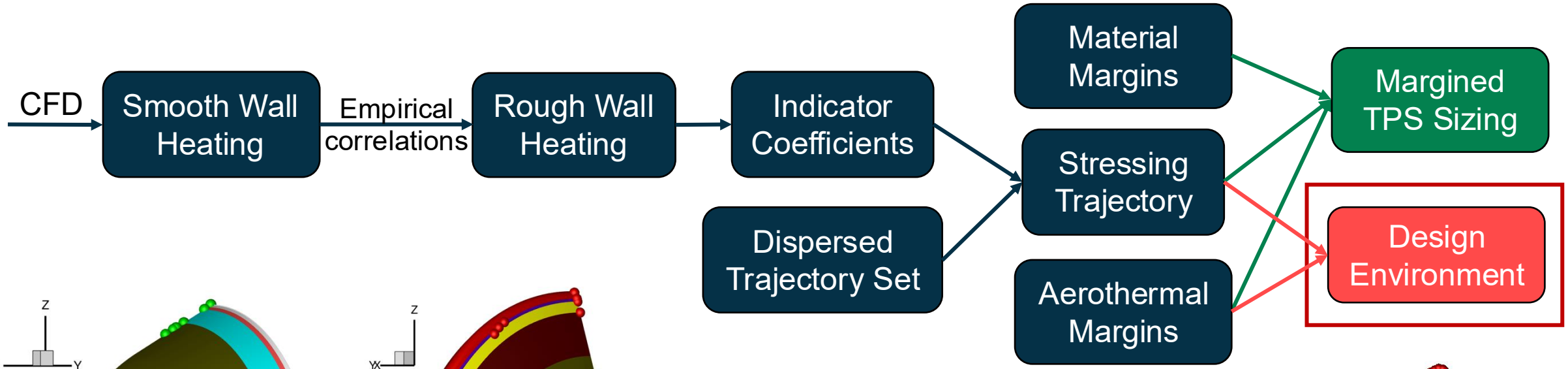
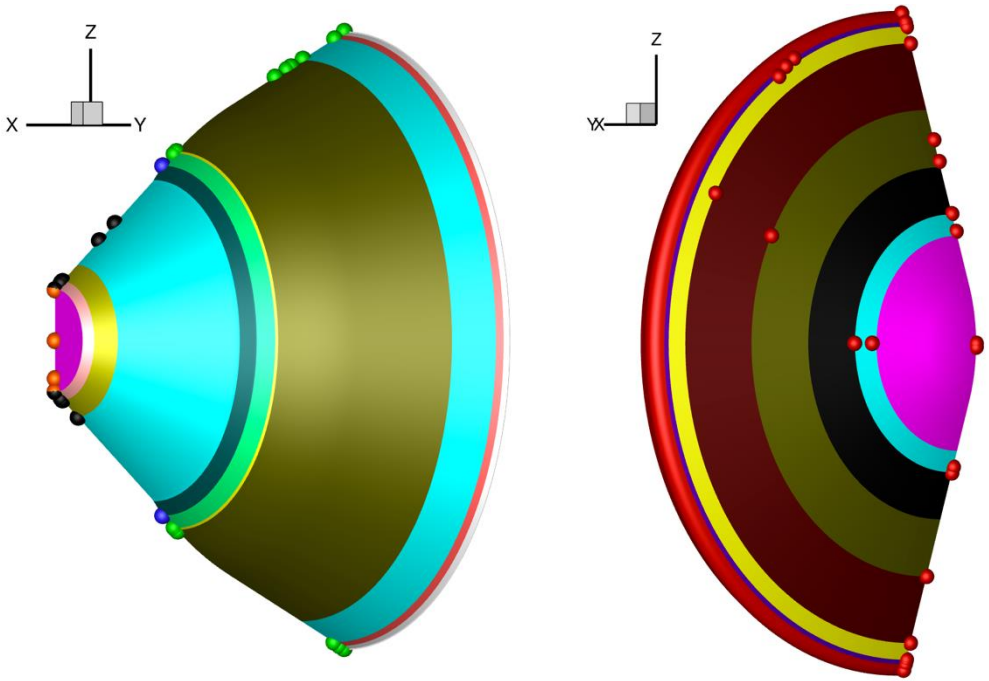
- Aerothermal margins are added on top of the stressing trajectory environment to inform design environments
  - Aftbody design environments are identified in the same way as described for the forebody, but the smooth CFD solution is used (no roughness augmentation)

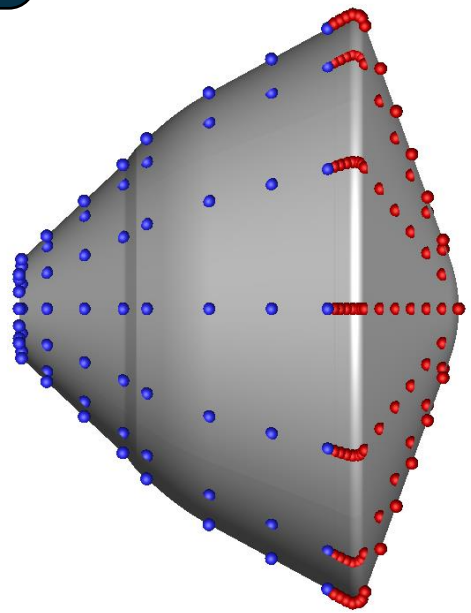
	Aerothermal Margins	
	Forebody	**Aftbody**
Convective heat flux (q_{conv})	1.22	2.0
Radiative heat flux (q_{rad})	1.5	1.47
Pressure (P_w)	1.05	1.25
Shear stress (τ_w)	1.25	1.5

- The margin table is derived from Mars 2020
- Path to CDR envisioned
  - SRL-specific margins using a framework that includes parametric uncertainty analyses, ground-test comparisons, and code-to-code comparisons
  - Refining/modifying uncertainties due to aftbody features and RCS thrusters

Design Environment and TPS Sizing

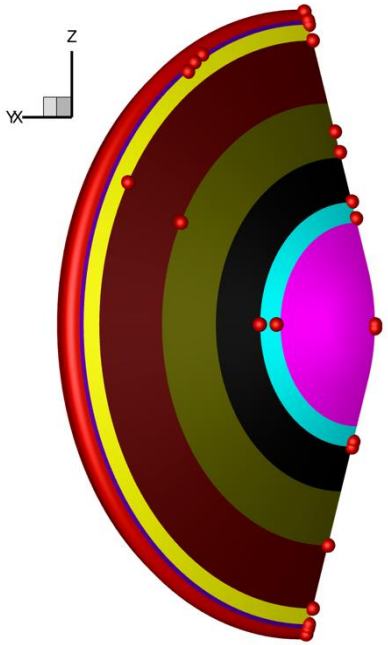




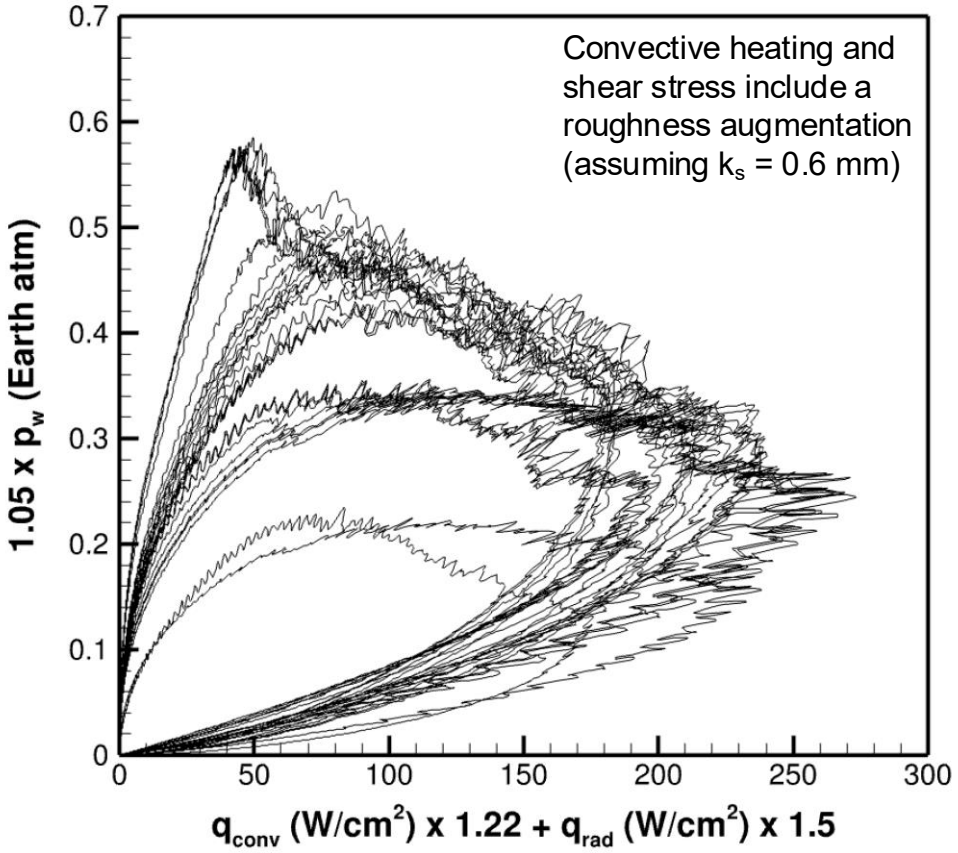


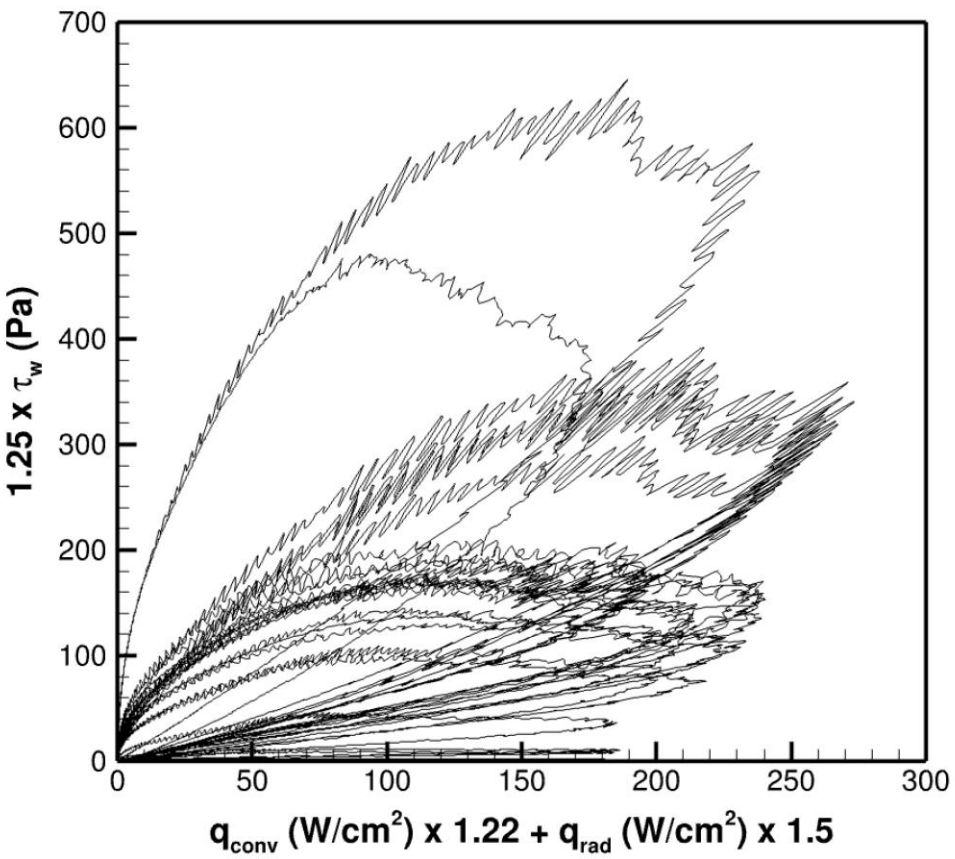
Design Environments

- Butterfly plots below show stressing environments at each body point with an added aerothermal factor to further margin the environment
  - Informs TPS material testing approach

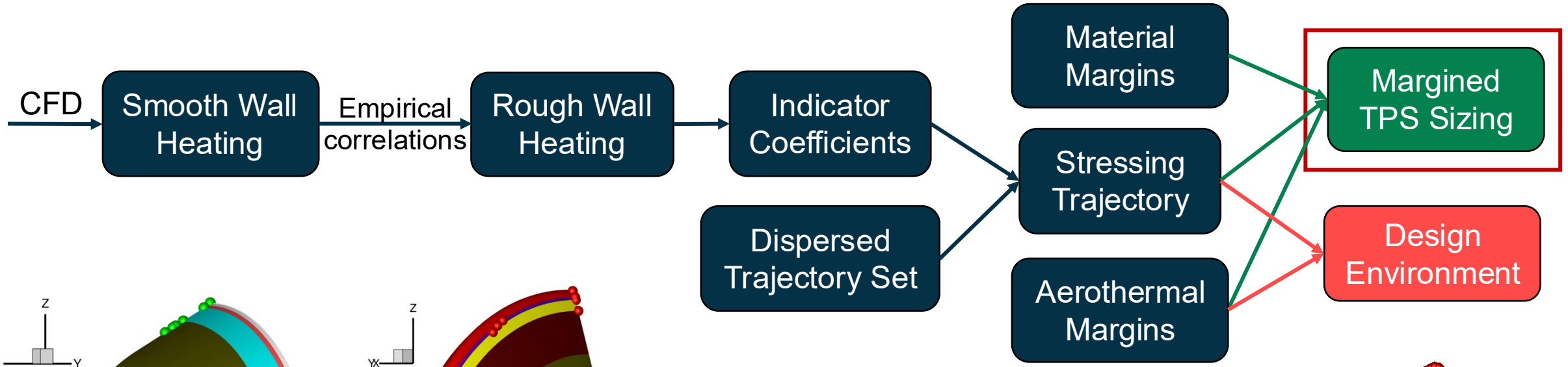


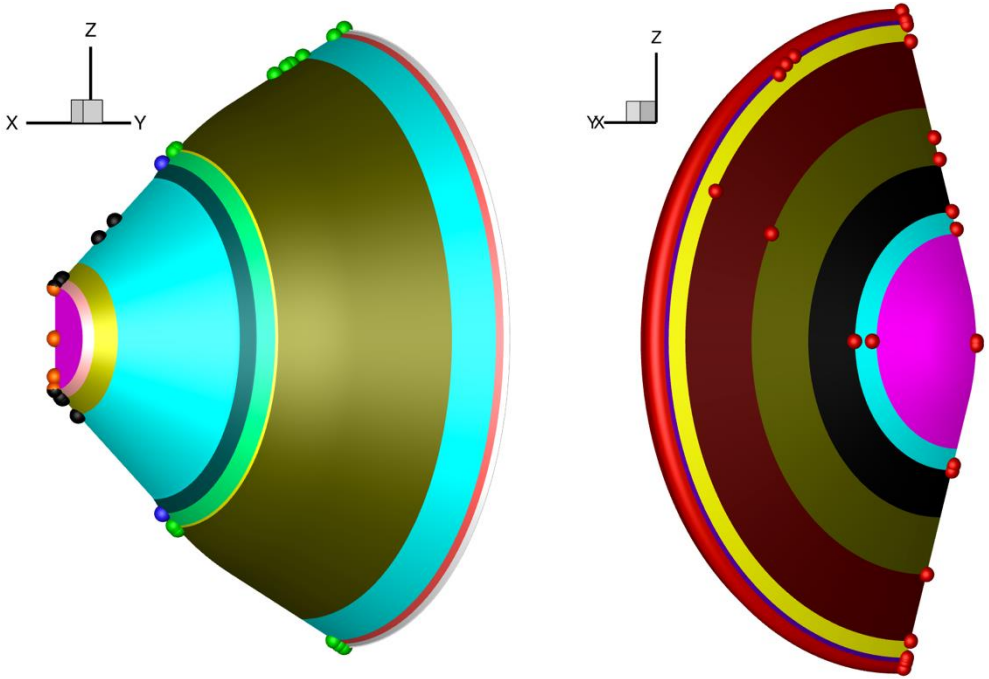
Heatshield

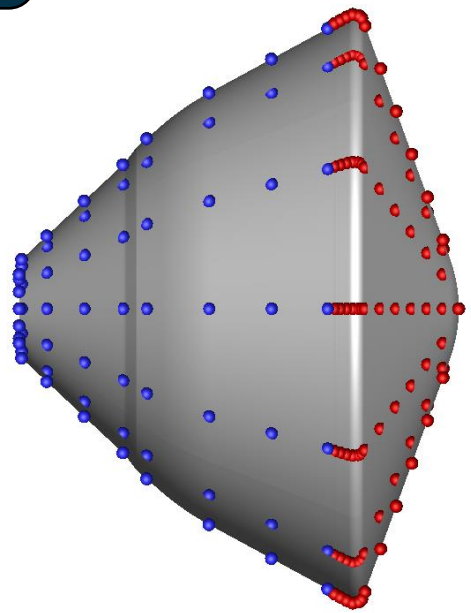




Design Environment and TPS Sizing





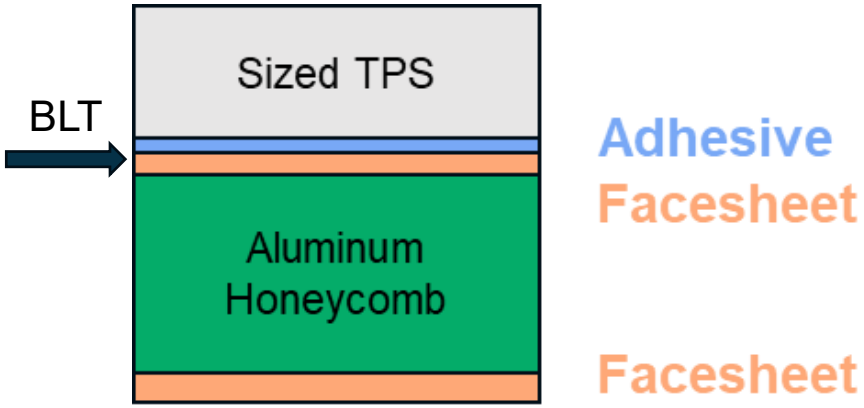


TPS Sizing

- Sizing was done using the traditional three branch approach
  - T_1: Nominal branch – calculated using the unmargined environment and the unmargined bond line temperature limit
  - T_2: Aerothermal branch – calculated using the margined environment and the unmargined bond line temperature limit
    - Accounts for uncertainties in aerothermal analysis
  - T_3: Material branch – calculated using the unmargined environment and the margined bond line temperature limit
    - Accounts for variability in material properties
  - T_{RSS}: Margined thickness – calculated as

$$T_{RSS} = T_1 + \sqrt{(T_2 - T_1)^2 + (T_3 - T_1)^2}$$

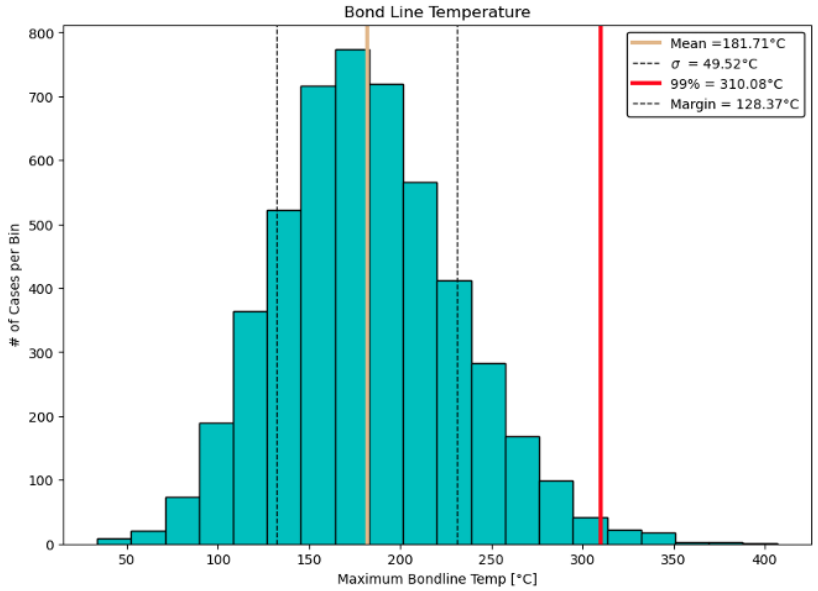
  - T_{final}: Includes 20% recession margin (for ablating materials), manufacturing tolerance, and any other required design features (e.g., facesheet overwrap) on top of T_{RSS}

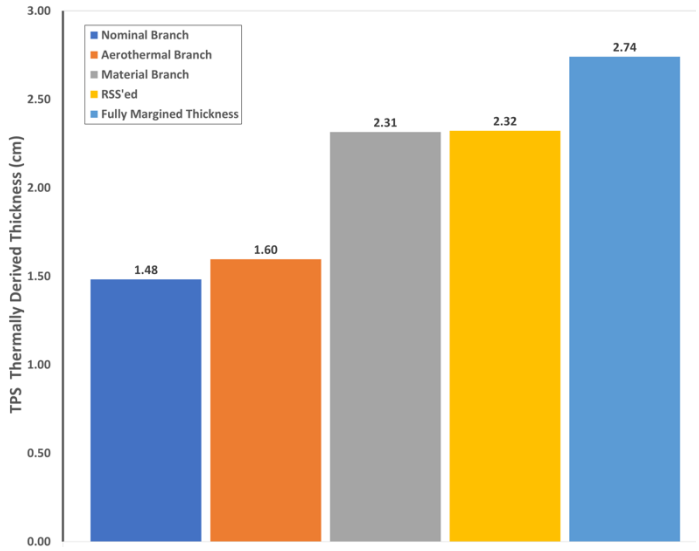


- Current SRL analysis does not include NuSil in the TPS sizing process
  - Future work will study the impact of NuSil at regions of the heatshield with lower heating, and inform mass loss estimates during flight

Bondline Temperature Margin

- Margin applied to BLT in the material branch is estimated with a FIAT Monte Carlo analysis
  - 8000 FIAT cases were run with varying TPS and substructure material properties
- Initial material property uncertainties used were identical to Mars 2020 analysis, but recent PICA-D testing showed increase in uncertainty of density and thermal conductivity
  - Increased BLT margin from 80°C to 128°C
    - Material margin dominates RSS thickness calculation



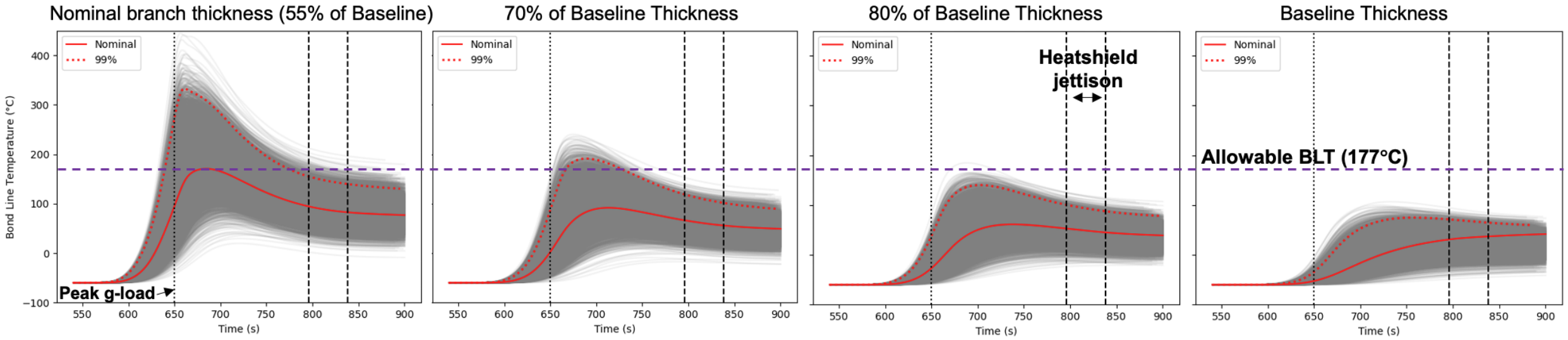


PICA				
Parameter	MSL	OSIRIS-Rex	Mars 2020	SRL *PICA-D
Virgin				
Density	5	5	5	11.2
Specific Heat	5	10	5	5
Conductivity	15	28	20	31.9
Emissivity	5	5	5	5
Char				
Density	7	Same as Virgin	Same as Virgin	Same as Virgin
Specific Heat	10	10	10	10
Conductivity	10	Same as Virgin	Same as Virgin	Same as Virgin
Emissivity	5	5	5	5
Other				
Recession	8	20	8	8
Decomp Para.	20	20	20	20
Blowing Reduction	20	0	20	20
Pyrolysis Gas Enthalpy	25	25	25	25
Initial Temp	0	0	0	0

*2σ uncertainties as a percentage of mean value

Alternative Margining Strategy

- Varied TPS and substructure material properties, aerothermal uncertainty, recession factor, and trajectory
  - Material property uncertainties – Gaussian distributions from Mars 2020 + new PICA-D testing
  - Aerothermal uncertainties – uniform distributions between 1 and aerothermal margins (slide 6)
  - Recession factor – Gaussian distribution centered around 1 with standard deviation of 0.1
  - Trajectory dispersions – 8001 trajectories from flight mechanics team
- Ran FIAT with full design thickness and reduced thicknesses and calculated BLT



Alternative Margining Strategy

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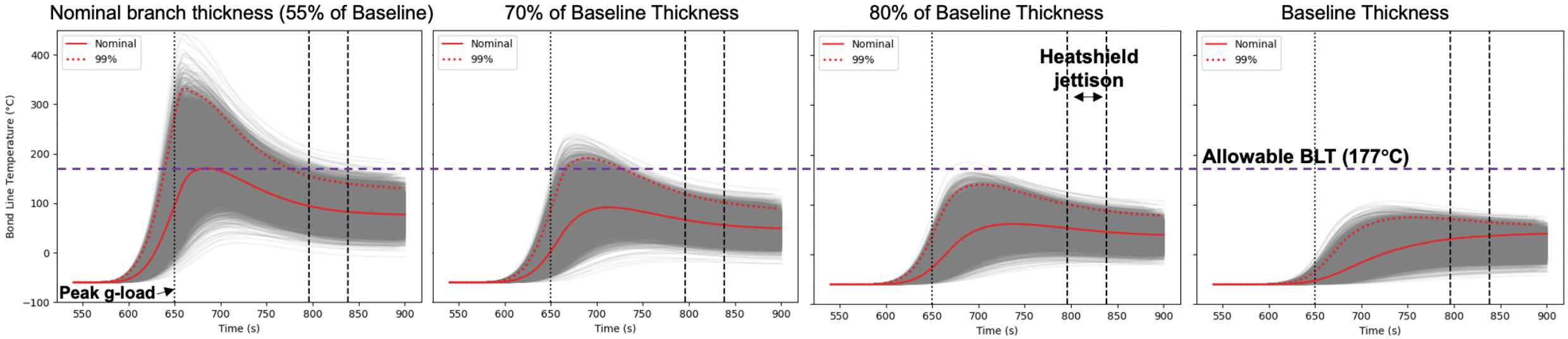
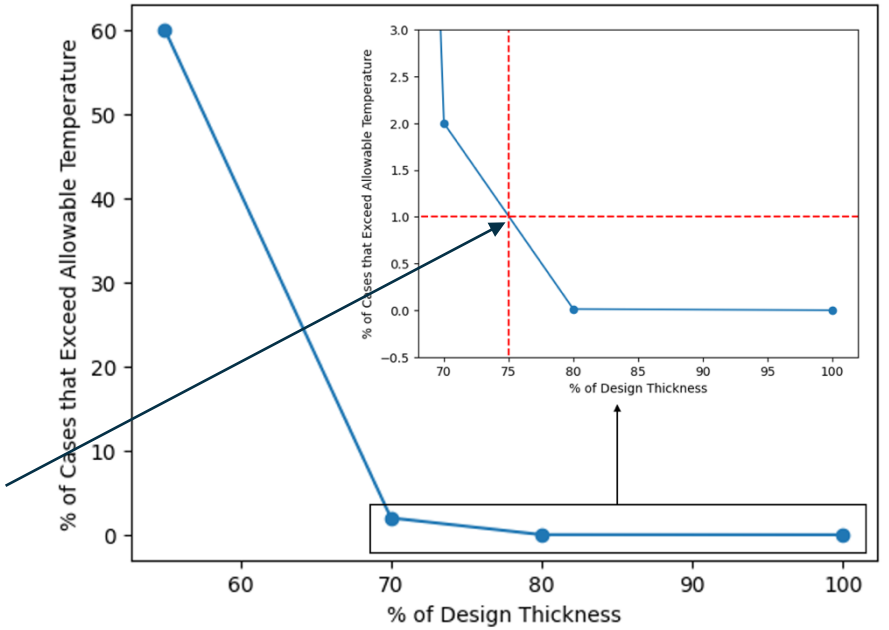


Percent of Baseline Design Thickness	Number of Cases Exceeding 177°C	99th Percentile Case Peak Temperature	99% Margin
100%	0	75°C	102°C
80%	1	140°C	37°C
70%	160	191°C	-14°C
55%	4800	333°C	-156°C



- Thickness of ~75% of baseline design thickness would result in 99% confidence in BLT remaining below allowable

Sensitivity to Monte Carlo Parameters

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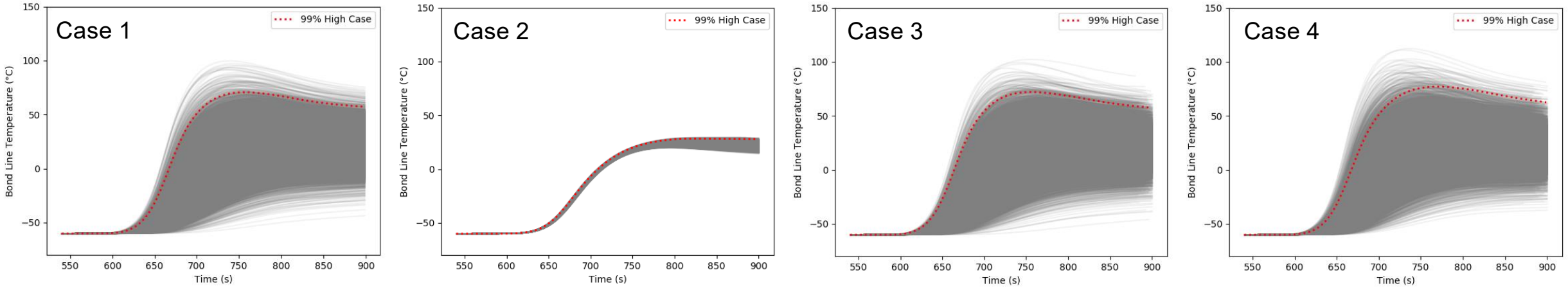
- Four Monte Carlo analyses were performed with different parameters varied



	Dispersed Trajectory	Material Properties	Aerothermal Uncertainty
Case 1		X	
Case 2	X		
Case 3	X	X	
Case 4	X	X	X

	Mean Peak BLT	Standard Dev Peak BLT	99th Percentile Peak BLT
Case 1	25.2°C	18.7°C	70.7°C
Case 2	24.2°C	2.0°C	28.3°C
Case 3	25.5°C	19.1°C	72.3°C
Case 4	27.6°C	19.7°C	77.4°C

- Trajectory dispersions alone do not significantly affect peak BLT, while material property uncertainties have a very large impact

Conclusions and Future Work

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Conclusions

- Demonstrated framework to identify stressing trajectories from dispersed trajectory set and turn them into design environments
- Explored new margining approach – suggested that traditional TPS design thickness may be overly conservative

Future Work

- TPS sizing for special features and RCS plume impingement heating
- Monte Carlo analysis across the rest of the aeroshell
  - Assess time at which BLT exceeds allowable and location on aeroshell to evaluate consequences of thinner TPS