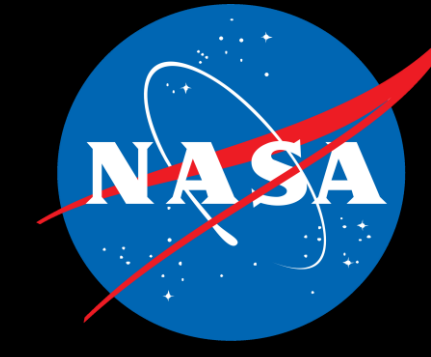




Aerothermal Analysis of the Dragonfly Titan Entry

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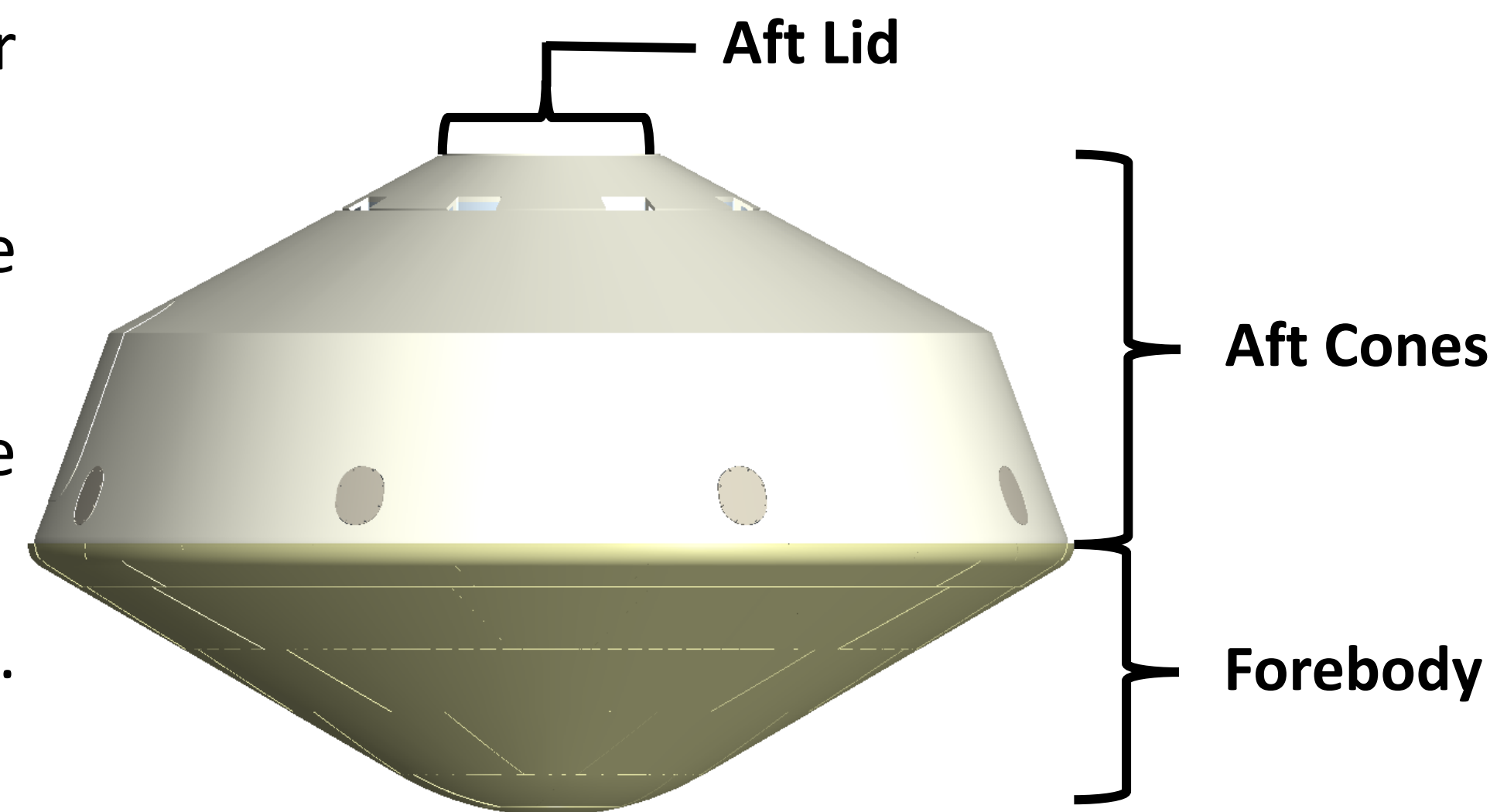
Introduction

Dragonfly is an upcoming NASA New Frontiers mission that will send a rotorcraft lander to Saturn's moon Titan [1]. This will be the first spacecraft to land on Titan since the Huygens probe's descent in 2005 and only the second spacecraft overall to enter Titan's atmosphere. With its dense N₂ atmosphere containing trace amounts of CH₄, Titan provides a unique entry environment with an unusually long entry sequence and significant radiant heating at relatively low velocities. To address these challenges, the Dragonfly entry capsule design is informed by state-of-the-art aerothermodynamic analysis tools and methodologies that will be laid out in this poster.

Entry Overview

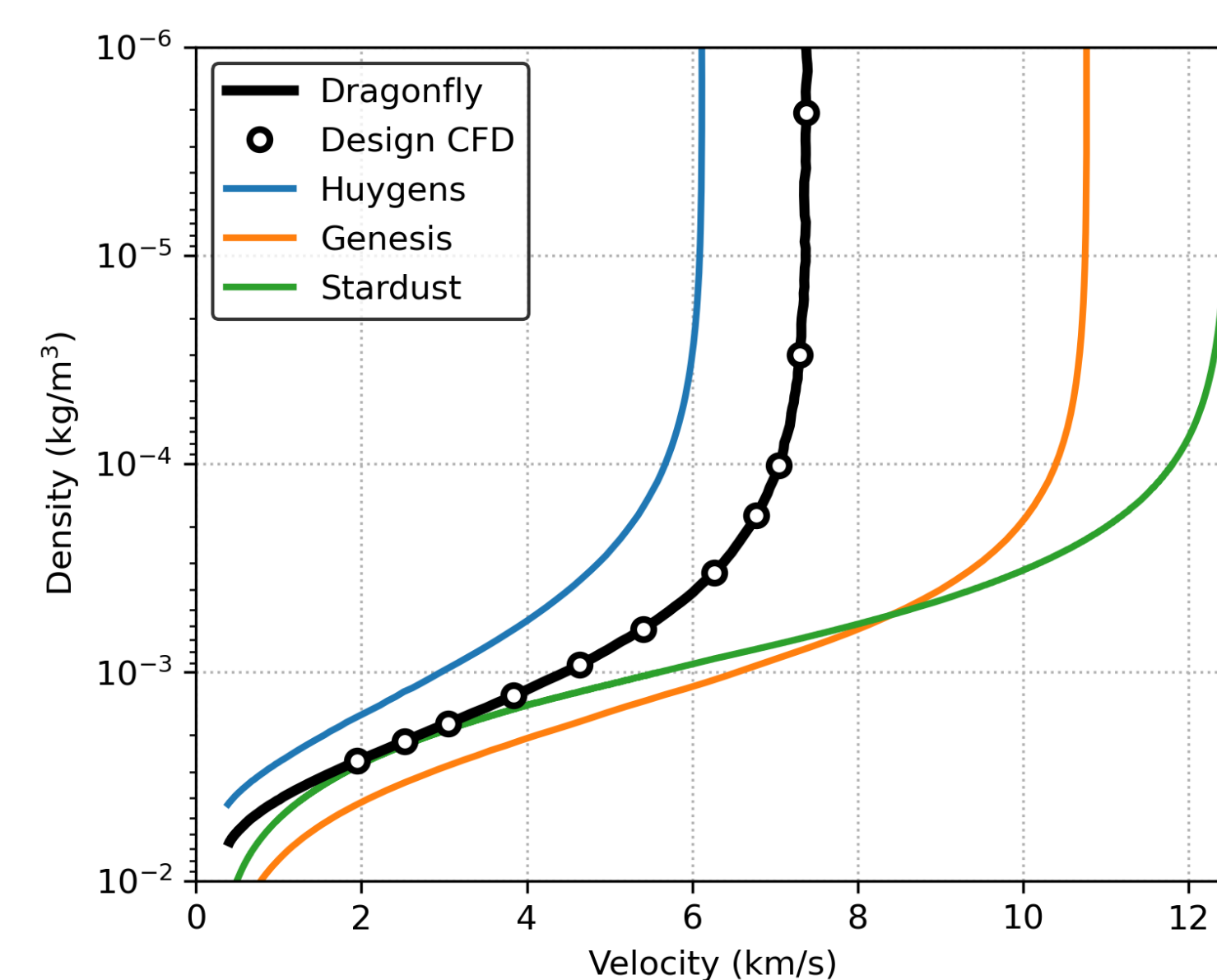
The rotorcraft is delivered to Titan in a 4.5m diameter aeroshell. Key entry features include:

- **Ballistic entry** in a scaled-up Genesis capsule (pictured to the right).
- **Long entry sequence**, 105 minutes to lander release (compared to "7 minutes of terror" on Mars).
- **Significant radiant heating**, ~37% of peak stag. point heating, up to ~90% of heating on aft cones.



Nominal Entry Conditions for Representative Planetary Science Missions [2]

Trajectory Parameter	Dragonfly	Huygens	Genesis	Stardust
Planetary Destination	Titan	Titan	Earth	Earth
Entry Velocity (km/s)	7.3	6.0	10.8	12.5
Entry Flight Path Angle (deg)	-48.0	-65.5	-8.0	-8.2
Vehicle Mass (kg)	2310	320	210	46
Ballistic Coeff (kg/m^2)	70	35	80	60
Peak Dynamic Pressure (kPa)	9.19	4.64	21.39	18.81
Heat Pulse Width (s)	180	128	87	81
Stag-Point Heat Load (kJ/cm^2)	7.6	1.4	16.6	26.2
% Radiant to Total Stag. Point Heating	37	0	5	8



Engineering Correlations

Built upon functional forms used for Mars 2020 [3] to quickly estimate heating.

- Fit to computational fluid dynamics (CFD) predictions at specific aeroshell locations.
- Incorporate post-shock conditions with the Chemical Equilibrium Analysis (CEA) tool.
- Determine probabilistic heating with Monte Carlo trajectory simulations.

Maximum Possible Value (MPV) Vehicle Mass Entry Statistics

Statistic	Peak Margined Total Heat Flux (W/cm^2)	Peak Margined Total Heat Load (kJ/cm^2)
Nominal	238.55	11.63
Mean	237.68	11.67
+99%	250.95	12.16
+99.87%	255.31	12.33
Max	261.06	12.68

$$q_{conv} = A \times (10^3 \times \rho_{\infty})^B \times \left(\frac{v_{\infty}}{10^3}\right)^C \times \left(\frac{T_2}{10^3}\right)^D$$

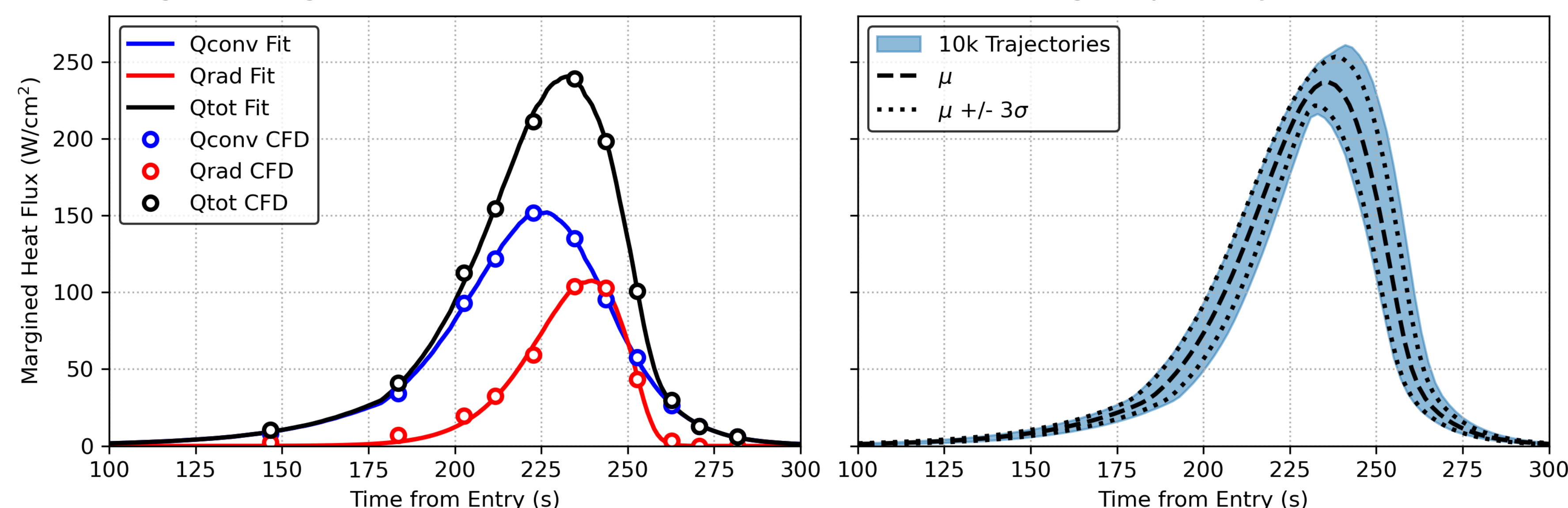
$$q_{rad} = A \times \left(10^7 \times \frac{\rho_2 \times Y_{CN,2}}{\rho_{\infty}^2 - 1}\right)^B \times \left(\frac{T_2}{10^3}\right)^C$$

New term to account for shock-layer thickness

Variable Definitions

q_{conv}	Convective Heat Flux (W/cm ²)
q_{rad}	Radiative Heat Flux (W/cm ²)
ρ_{∞}	Freestream Density (kg/m ³)
v_{∞}	Freestream Velocity (m/s)
T_2	CEA Equilibrium Post-Shock Temperature (K)
ρ_2	CEA Equilibrium Post-Shock Density (kg/m ³)
$Y_{CN,2}$	CEA Equilibrium Post-Shock CN Mass Fraction

Engineering Correlations Fit to CFD and Evaluated along Trajectory Monte Carlos

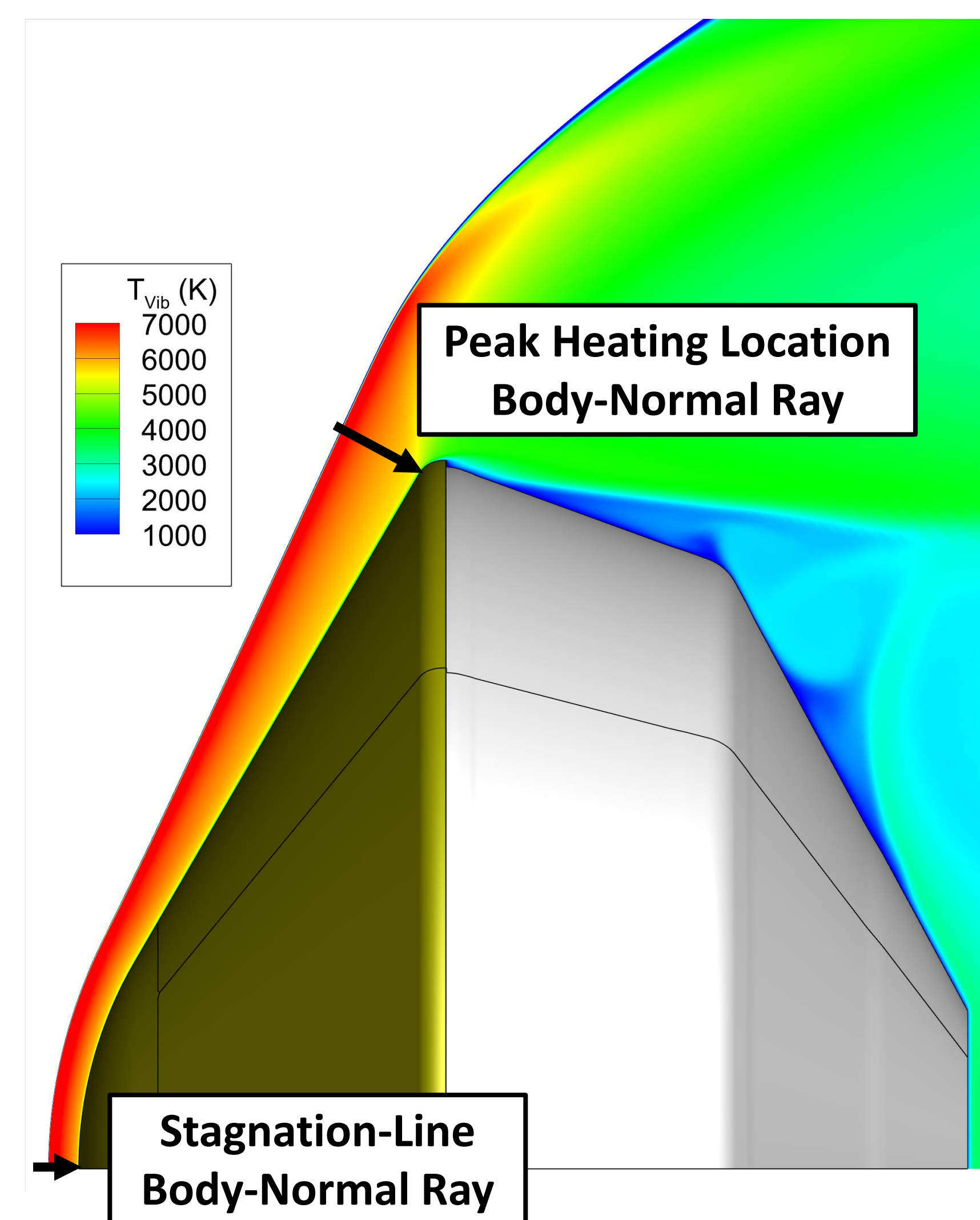


Aerothermal Modeling

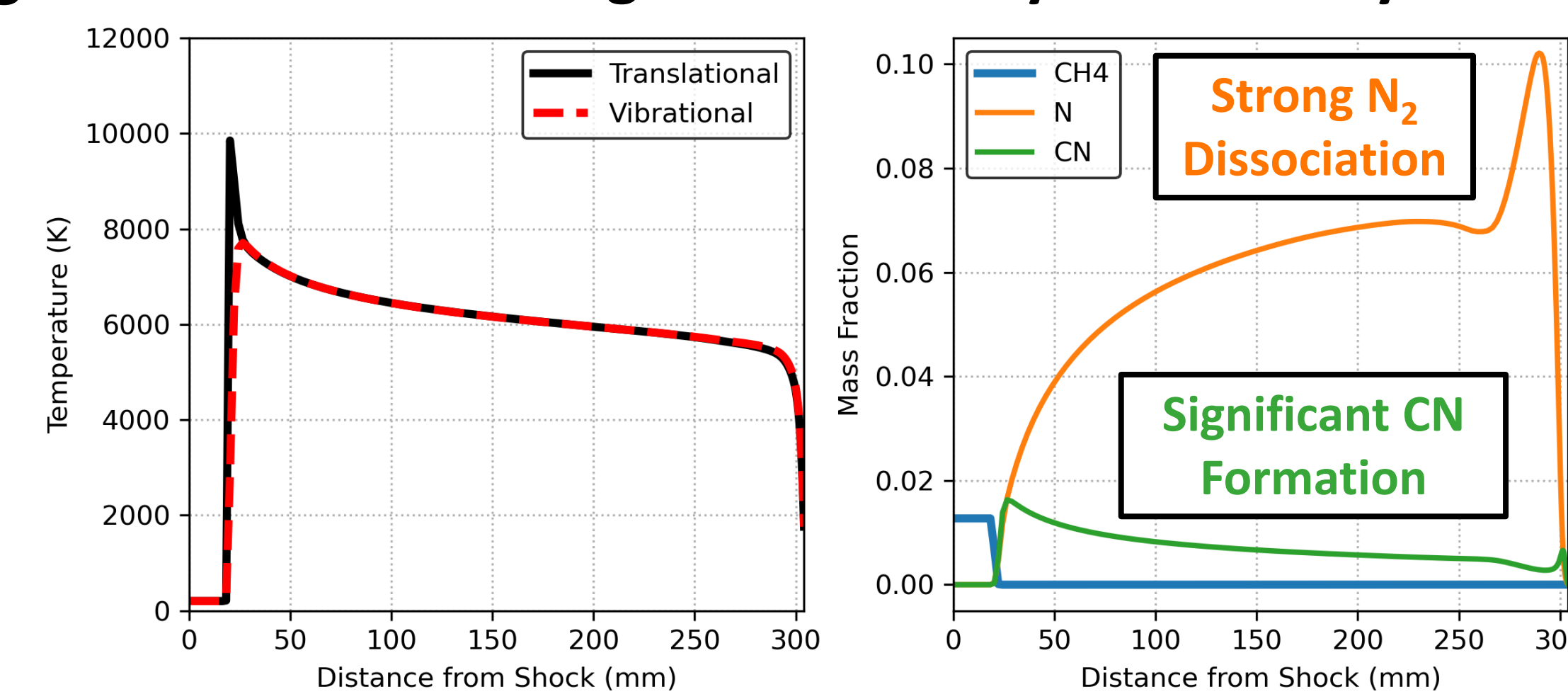
Flow Field: Hypersonic flow fields are calculated with the Data-Parallel Line Relaxation (DPLR) computational fluid dynamics (CFD) code developed at NASA Ames Research Center. All design solutions are axisymmetric with shock-aligned grids. Key modeling features include:

- Two-temperature thermal nonequilibrium.
- Finite-rate chemistry governed by a 21-species Titan atmosphere model.
- Fully-catalytic wall at radiative equilibrium.
- Fully-turbulent flow calculated with the SST-2001 model.
- Flow fields include radiative energy losses using weak coupling with the Nonequilibrium Radiative Transport and Spectra Program (NEQAIR).

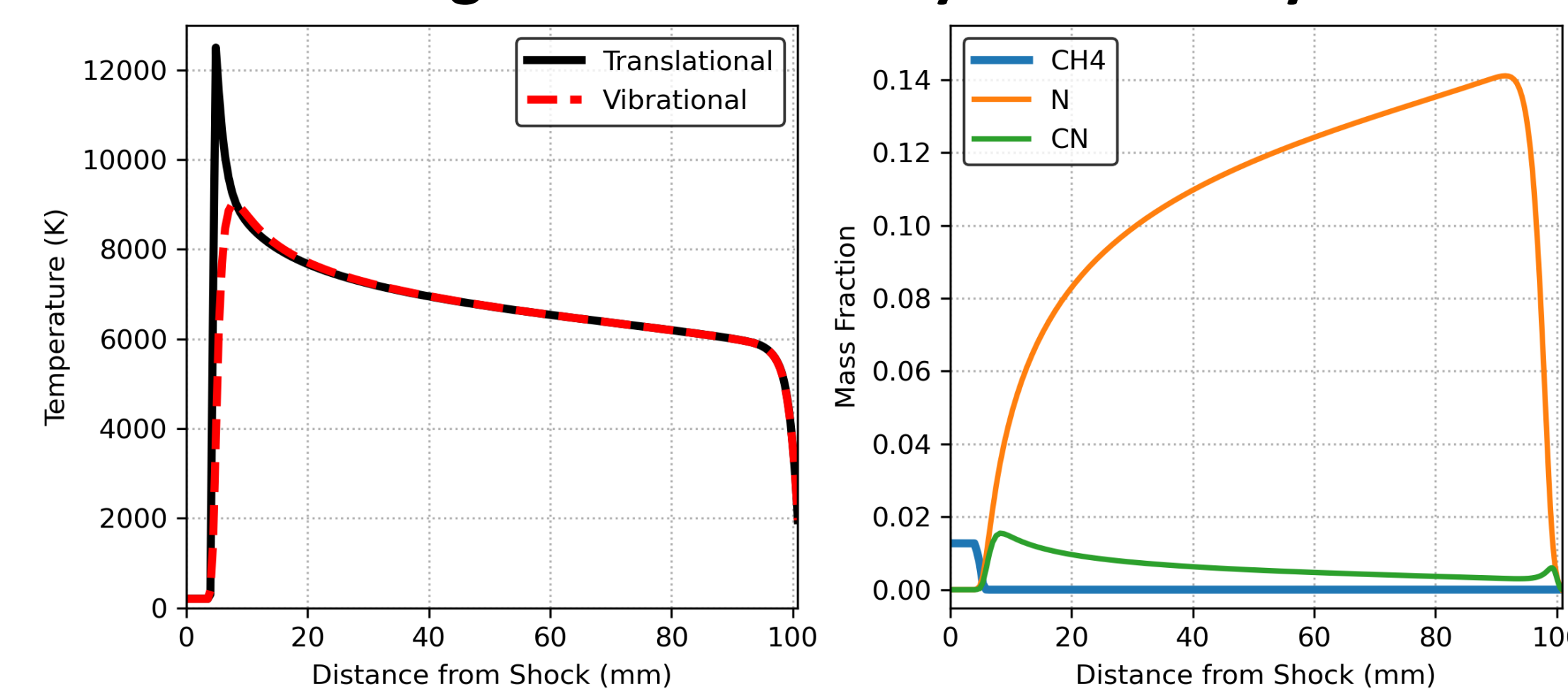
Flow-Field at the Time of Peak Total Heating



Peak Heating Location Body-Normal Ray



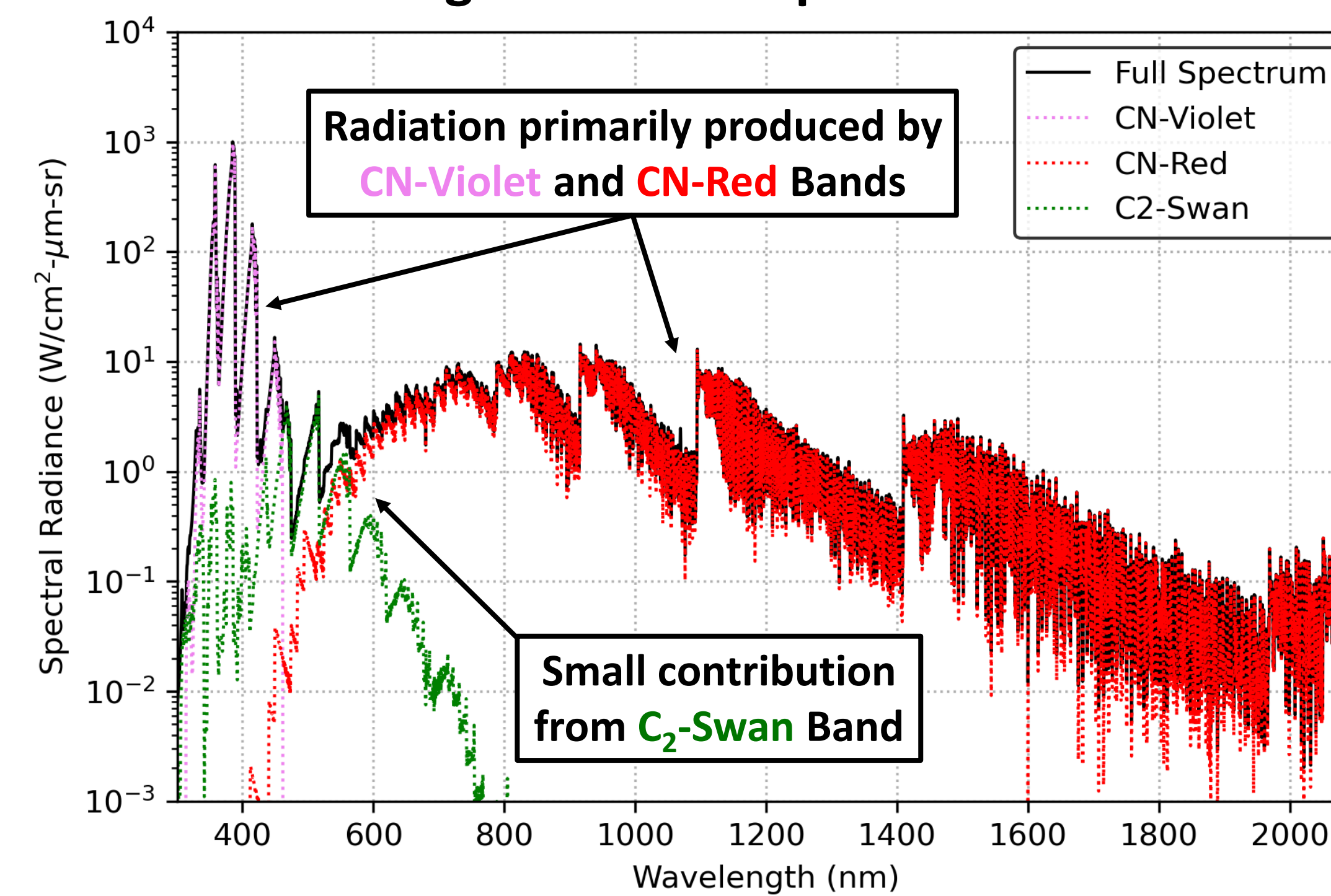
Stagnation-Line Body-Normal Ray



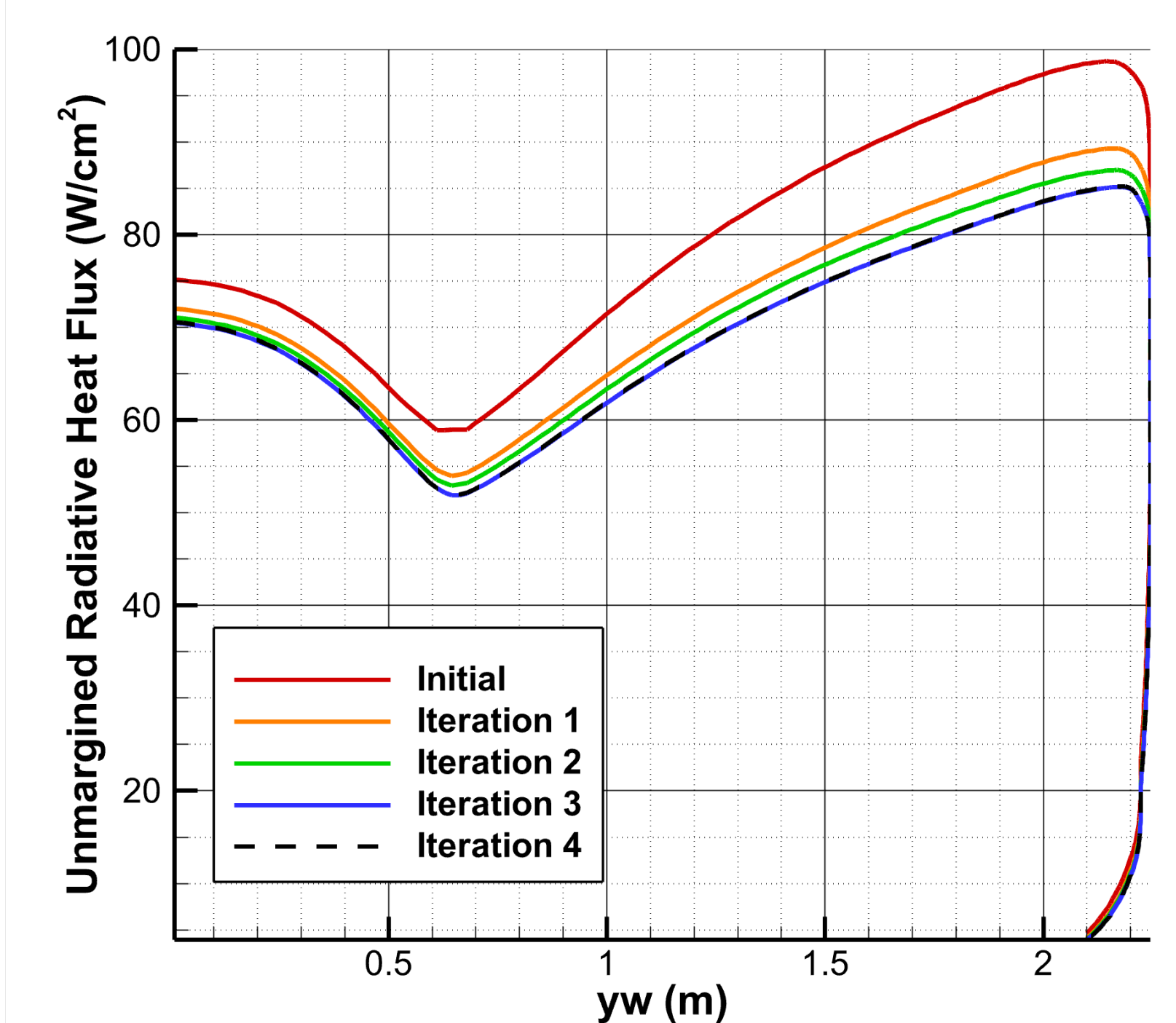
Radiative Heating: Radiant heating is modeled with the NEQAIR radiation-transport code developed at NASA Ames Research Center. All radiative-heating calculations use 3D-hemispherical integration over solid angle.

- Radiation is dominated by the CN molecule formed through the decomposition of CH₄, so heating is highly sensitive to freestream CH₄ concentration (use conservative 2.2% by volume).
- Significant forebody heating contribution (~40%), dominant in upper-aft cones heating (~90%).
- Radiative-energy loss computed by iteratively passing species and temperatures to NEQAIR to compute the radiation-loss term for DPLR.

Stagnation-Line Spectral Radiance



Coupling Shock-Layer Radiation with Flow Field Calculations



References

- [1] J. Barnes et al. (2021). *Science Goals and Objectives for the Dragonfly Titan Rotorcraft Relocatable Lander*. The Planetary Science Journal, 2:130, August.
- [2] K. Parcero et al. (2022). *PLANETARY MISSION ENTRY VEHICLES Quick Reference Guide Version 4.0*. NASA Special Publication 20220010761.
- [3] A. Brandis, C. Johnston, and K. Edquist. (2018) *Radiative Heating Indicators and Uncertainty Analysis for Mars2020*. [Presentation]. AIAA Aviation Forum, 25-29 June, Atlanta, Georgia.