SIGNIFICANCE OF DSMC COMPUTED AERO THERMAL ENVIRONMENTS IN THE RAREFIED REGIME FOR ATMOSPHERIC ENTRY MATERIAL RESPONSE


Introduction

During Mars atmospheric entry, the Mars Science Laboratory (MSL) was protected by a 4.5-meter diameter ablative heat shield assembled in 113 tiles [1]. The heat shield was made of NASA's Baghdad ablative material, the Phenolic Impregnated Carbon Ablator (PICA) [2]. Prior work [3] compared the usual one-dimensional and three-dimensional material response models at different locations in the heat shield. It was observed that the flow was basically one-dimensional in the nose and flank regions, but three-dimensional flow effects were observed in the outer flank.

Aerothermal environments from SPARTA and DPLR

The MSL flight environment was simulated using the following assumptions for both the CFD and DSMC simulations:
- Super-catalytic wall BC: CO₂ and N₂ recombination to freestream mole fractions
- Radiative equilibrium wall with χ = 0.89
- Mars atmosphere Ye = 0.97 and YO₂ = 0.03
- 8 species and 24 reactions (12 forward + 12 backward): Mitchelltree model [6]
- PARK hyperonics correction to vibrational relaxation

Material response from PATO

The Porous material Analysis Toolbox based on OpenFOAM (PATO) [10, 11] is used for the material response calculations. The governing equations are volume-averaged forms of solid mass, gas mass, momentum, and total energy conservation, including pyrolysis gas production. The thermodynamics and chemistry properties are computed using the Multiphase library [12]. The boundary conditions at the heat shield front surface are interpolated in time and space from the aerothermal environment at discrete points of the MSL trajectory [3], using a Galerkin projection. For this study, the Theoretical Ablative Composite for Open Testing (TACOT) database code developed by the TPS community was used to define the porous material properties. TACOT is a fictitious material that was inspired from low density carbon/phenolic ablators. The boundary layer (BL) quantities from DPLR are extracted using a curvature-based method with the BLAYER code [9]. For the DSMC results, a Boundary Layer utility was created in PATO and an edge-based method was used (location of BL such that hₐ = 0.05%). The turbulent environment case strongly increases the surface temperature compared to laminar environment, and relocates the area of maximum temperature from the nose to the leeside flank (Fig. 5). We compute the material response of the MSL heat shield in a monolithic 3D configuration, with the Martian aerothermal environments derived from DPLR only and DSMC+DPLR. The laminar and turbulent solutions are in agreement until 50 s of EL, however, the surface temperature reaches values up to twice higher in the case of the turbulent environment (Fig. 6). For MISP4, in-depth thermal effects are as important as surface thermal effects especially before 60 s (Fig. 7). Fig. 8 shows the surface recession computed in PATO with the highest recession at MISP5 as expected for a laminar aerothermal environment, and at MISP2.3 for a turbulent aerothermal environment. This recession is 4 times larger for the turbulent environment. Almost no recession is observed before 60 s due to the low heat flux. Only subtle differences in the recession are found between DPLR only and DSMC+DPLR derived environments.

References