DSMC Modeling of Rarefied High-Enthalpy CO2/N2 Flows

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An accurate prediction of heat fluxes on space vehicles in the Martian CO_2 atmosphere requires improvement of physical models and CFD codes, which are to be validated with experimental data in ground-based facilities. Such activities are currently performed within the framework of the SACOMAR (Key Technologies for Safe and Controlled Martian Entry) project of the European Union FP7 program. In addition to experimental studies in three different high-enthalpy facilities, a code-to-code comparison is carried out using the model geometry of ground testing (flat-faced cylinder with rounded edges) under real flight conditions.

As for the case of the Earth entry, the continuum approach based on Navier-Stokes equations is inapplicable for high-altitudes aerothermodinamic predictions in the Martian atmosphere due to rarefaction and thermal nonequilibrium effects; therefore, the Direct Simulation Monte Carlo (DSMC) method [1] should be employed in the computations. In the SACOMAR project, the area of applicability of conventional CFD methods and validity of results obtained with continuum codes for high-altitude trajectory points are assessed by comparisons with DSMC results obtained by the SMILE (Statistical Modeling In Low-density Environment) software system developed at ITAM [2].

A characteristic feature of DSMC simulations under the Martian entry conditions is the significant intricacy of modeling of inelastic collisions due to the presence of polyatomic species and a large number of chemical reactions and energy transfer processes (see, e.g., [3]). Another difficulty is correct modeling of surface chemistry, which is crucial for predicting heat fluxes and is challenging even for the continuum approach.

The present paper is aimed at implementing into the SMILE system, verifying, and validating molecular models of the gas phase and surface chemistry applicable for DSMC computations of spacecraft aerothermodynamics in the Martian atmosphere. Extensive code-to-code validation has been performed with the SMILE and several continuum CFD tools (TAU code of DLR, TsNIIMash code, FLUENT, etc.). Cross-validation of the codes is performed for moderate-altitude conditions to ensure that rarefaction effects are insignificant, and then the rarefaction and thermal nonequilibrium effects are to be assessed by simulating the flow for high-altitude conditions with the SMILE and continuum codes. The results of these DSMC numerical studies as well as comparison with experimental results obtained in L2K high-enthalpy facility (DLR) will be presented in the full-length paper in detail.

Acknowledgments. The present study has been performed within the SACOMAR project funded by the European Commission under Grant agreement No. 263210.

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