Modeling of High-Temperature Weakly Ionized Flows with SMILE++ Software System

Ye.A. Bondar, A.A. Shevyrin, A.V. Kashkovsky, M.S. Ivanov

Computational Aerodynamics Lab
Khristianovich Institute of Theoretical and Applied Mechanics(ITAM) SB RAS
Institutskaya 4/1, Novosibirsk 630090, Russia

The Direct Simulation Monte Carlo (DSMC) is currently the main tool for predicting high-altitude aerothermodynamics of space vehicles, when the level of thermal and chemical nonequilibrium does not allow traditional continuum CFD methods to be employed. SMILE++ [1] is a software system for DSMC computations developed at the Computational Aerodynamics Lab of ITAM on the basis of principles of Object-Oriented Programming (OOP). SMILE++ is a descendant of the widely known SMILE code and incorporates most of the capabilities of the latter as well as many new ones. Recent efforts of the SMILE++ development are mainly inspired by the need of effective and accurate modeling of aerothermodynamics of superorbital reentry flight (with velocities higher than 10 km/s typical for Moon and planetary missions) as well as aerothermodynamics of large-scale spacecraft (ORION, PPTS, etc.).

The paper is mainly focused on the modeling of non-equilibrium chemical reactions/ionization and their impact on the convective and radiative heat fluxes to the spacecraft surface.

Modeling of non-equlibrium chemical reactions is known to be a source of great uncertainty in prediction of the spacecraft aerothermodynamics. A number of models for both DSMC and continuum simulations have been proposed but the lack of suitable experimental data makes it difficult to validate them and only a few steps have been made in this direction. The recent results on validation of the DSMC molecular chemical reaction models will be reviewed in the paper. The generic spacecraft aerothermodynamics will be numerically studied and the effects of the chemical reaction modeling on the convective and radiative heat fluxes will be assessed.

Reactions of associative ionization as well as ionization reactions by means of electron impact are of critical importance even at high altitudes in the case of superorbital reentry flight. To model the latter in the framework of the DSMC method electrons must be accurately simulated at the kinetic level. Due to huge differences in characteristic timescales between electrons and heavy particles, simplified models (such as ones proposed by Bird and Boyd) are usually employed in DSMC computations which do not imply the simulation of electron motion and collisions at the kinetic level. Another approach based on kinetic modeling of electrons trapped in the potential well is proposed in the present paper which provides more accurate description of the electron-impact ionization. The effect of the electron modeling on the spacecraft aerothermodynamics will be presented in detail in the full-length paper.

REFERENCES

[1] M.S. Ivanov, A.V. Kashkovsky, P.V. Vashchenkov and Ye.A. Bondar. Parallel Object-Oriented Software System for DSMC Modeling of High-Altitude Aerothermodynamic Problems (INVITED), AIP Conference Proceedings Volume 1333, 27TH INTERNATIONAL SYMPOSIUM ON RAREFIED GAS DYNAMICS, Pacific Grove, California, (USA), 10–15 July 2010, Edited by D. A. Levin, I. J. Wysong, and A. L. Garcia, pp. 211-218 (2011).