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"Reconsideration of the Majorant Collision Frequency Schemes for the DSMC Method"

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Abstract: It may be currently considered that a new independent CFD direction (computational rarefied gas dynamics) has been formed. The leading role here belongs to the Direct Statistical Monte Carlo (DSMC) method [1]. The conventional treatment of the DSMC method is based on considering the rarefied gas as a set of **N** particles with binary collisions and on the principle of splitting of continuous motion and collisions of rarefied gas molecules within a small time step **Δt** into two consecutive stages: free-molecular transfer and uniform collisional relaxation at the time interval **Δt**.

Numerical schemes for the DSMC method, based on the principle of the majorant collision frequency (MCF), were proposed in [2-4]. They were derived on the basis of the probability interpretation of the integral form of the master kinetic equation (Kac equation in the spatially uniform case and Leontovich equation in the spatially nonuniform case). The statistical estimated used in both uniform and nonuniform cases were proved there to be unbiased. It was demonstrated in [2-4] that these schemes are efficient because the computational cost is a linear dependence of the number of particles. More than 20-years experience of application of these majorant collisional frequency (MCF) schemes of the DSMC method for various problems of rarefied gas dynamics confirmed their high efficiency in solving multidimensional problems of high-altitude aerodynamics.

In the spatially uniform case, MCF scheme is "time-accurate", i.e., the parameter Δ**t** need not be introduced. For the spatially nonuniform case, numerical schemes of the DSMC method without splitting continuous motion and collisions of molecules into free-molecular transfer and collisional relaxation at the time interval **Δt**, i.e., the so-called "splitless" MCF schemes were also described in [3-4]. The computational efficiency of these schemes depends linearly on the number of particles, but they are more CPU-expensive than the schemes that involve the splitting principle (NCT, NTC, and MCF). The first example of using a "splitless" MCF schemes was described in [5] in solving the problem of the shock-wave structure.

The current stage of development of computational engineering allowed more extensive application of "splitless" MCF schemes for solving various problems of rarefied gas dynamics. In using these schemes, there is no need to demonstrate convergence of simulation results in terms of Δ**t**, in contrast to schemes of the DSMC method that involve the time parameter Δ**t**. In practical application of numerical schemes of the DSMC method for multidimensional flows, one of the main problems is to choose Δ**t**, which is the basic parameter of the method. Though they are CPU-expensive, "splitless" schemes allow obtaining benchmark results and checking whether Δ**t** was chosen correctly in traditional DSMC computations. Some results of numerical computations of classical problems of rarefied gas dynamics with the use of the "splitless" MCF schemes are presented in the talk, and the advantages of this scheme are demonstrated.

Bio: My current research involves theoretical validation of the Direct Simulation Monte Carlo methods for rarefied gas flows and development of new numerical schemes of the DSMC method. Much attention is paid to analysis of the connection of statistical simulation results with the solution of the Boltzmann equation. Effective numerical schemes of the DSMC method developed in my lab for rarefied flows allowed a significant expansion of the scope of problems of spacecraft aerothermodynamics with real gas effects. We performed a pioneering numerical study of the special features of the flow around concave bodies and efficiency of aerodynamic control surfaces at high flight altitudes. It was shown that excitation of vibrational degrees of freedom of molecules and chemical reactions change the qualitative flow pattern near concave bodies and significantly affect the efficiency of aerodynamic control surfaces.

During last 15 years, I was a Visiting Professor at various higher technical colleges and universities throughout the world. I was the Principal Investigator in many national and international research grants (RFBR, ISF, DFG, INTAS, ISTC, and CRDF).

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