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Separate modeling of trace species in hypersonic rarefied gas flows

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Trace species in hypersonic rarefied gas flows play an important role in predicting electromagnetic phenomena. A typical example appeared in the RAM-C II flight test: the mole fraction of trace species were several orders lower than those of primary species of the upcoming air flows, but dominated the electron density around the test vehicle. The DSMC method has been applied to the problem. In these studies, trace species were calculated simultaneously with primary species. To avoid too small and even none of simulated charged particles related with the trace species in computational cells, some special and artificial treatments were adopted, e.g. increasing the probabilities of associative ionization reactions by a factor of 120.

In light of trace species having little effect on primary species, a trace species separation (TSS) algorithm was proposed. According to this algorithm, firstly, the primary species of hypersonic rarefied gas flows are calculated by the DSMC method. Then, the trace species are calculated based on the reaction rates and primary species each cell. The motion of simulated particles of trace species are also calculated using the DSMC method, with collisions mainly with those of primary species generated based on their number density, velocity, temperatures obtained in the first step.

The TSS algorithm makes it much easier to obtain trace species distribution around a hypersonic vehicle at high altitude (Fig.1). The electron density given by this method at the RAM-C II flight test condition of altitude of 81 km agrees well with the measured data, where q is a translational-vibrational temperature factor for associative ionization reactions, with a recommended range between 0.3 and 0.5. The present study demonstrates that Park's reaction model as q is equal to 0.4 worked nicely in predicting the electron density of hypersonic rarefied gas flows.

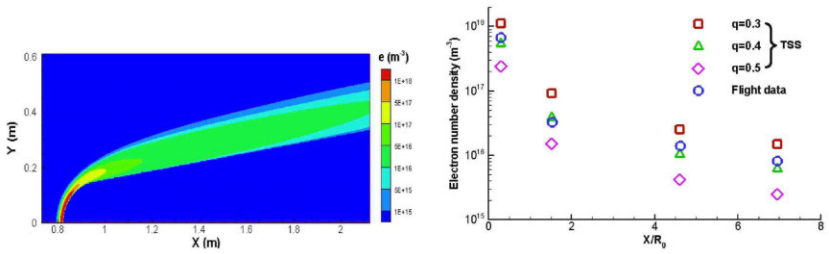

Fig. 1 Electron density distribution around a blunt cone given by the TSS algorithm at the RAM-C II flight test conditions (left), and its comparison (right) with the measured data