Spectral Modeling of Gas Radiation in Hypersonic Nonequilibrium Flows

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Space vehicles entering from outer space into atmospheres of planets are subjected to intense radiative heating from hot ionized plasma in the shock-layer. Accurate prediction of the radiative heat load is one of the most important challenges in the design of the thermal protection system of the spacecraft.

Calculation of gas radiative properties in nonequilibrium plasmas is a very complicated and computationally expensive task. A large number of processes, such as photo-dissociation, photo-ionization, etc., make these calculations extremely difficult. The state of the gas is generally in thermal and chemical nonequilibrium. A large number of atomic and molecular radiating species and non-Boltzmann distributions of populations of various energy modes make it very difficult to represent the gas properties correctly.

Most radiative transfer calculations in hypersonic plasmas have focused on calculating the gas radiative properties at a large number of wavelengths and solving the Radiative Transfer Equation (RTE) in a line-by-line (LBL) fashion. The LBL method is the most accurate method as it solves the RTE at all wavelengths; however, it is prohibitively expensive for coupled flow–radiation simulations.

The *k*-distribution method is a class of methods where the erratically-varying spectral absorption coefficients are reordered into a monotonically increasing function. This monotonic function allows efficient integration of radiative intensity over the spectrum, saving computer time by a huge factor of more than 1000 over the LBL method. Application of the existing *k*-distribution models to hypersonic plasmas poses a number of new challenges due to extreme temperature and concentration gradients, thermodynamic nonequilibrium and presence of a large number of gaseous species. In this work, a number of new *k*-distribution models have been developed for hypersonic plasma. These models utilize state-of-the-art spectroscopic data and chemical rate coefficient for the calculation of required gas properties. To utilize the full potential of the *k*-distribution method, pre-calculated values of *k*-distributions are stored in databases, which can later be interpolated at local flow conditions.

A large percentage of radiative energy emitted in the shock-layer is likely to escape from the region, resulting in cooling of the shock layer. This may change the flow parameters in the flow field and, in turn, can affect radiative as well as convective heat loads. My current research work focuses on coupled flow–radiation simulation of a spacecraft entering into the atmosphere of Mars. I am utilizing exiting chemistry models, numerical schemes and solvers in OpenFoam (an open source CFD code) along with the addition of new *k*-distribution models to solve the complex flow problem.

Radiative heat transfer in hypersonic plasmas is one of the most interesting areas for research from Indian context. A number of project of the Indian Space Research Organization, viz., Reusable Launch Vehicle-Technology Demonstrator (RLV-TD), Hypersonic Flight Using Air Breathing Propulsion, Supersonic Combustion, etc. require accurate prediction of radiative heat loads and its feed back to the flow. The major objective of the research will be to develop computational tools for the above-mentioned applications; modeling fluid mechanics, chemistry, radiation, , turbulence and turbulence radiation interaction.