Vibrational kinetics in 2D High enthalpy flows using GPU's

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Abstract. A 2D fluid dynamic code, 2D-FSGba, including non equilibrium air kinetics in both state-to-state (StS) and multi-temperature (MT) approaches, implementing MPI-CUDA instructions, can run on multi-GPU machines. This tool has been applied to high enthalpy flows around blunt and sharp bodies, speeding-up the calculation by a factor 100, with respect to multi-CPU, when the StS model is used.

Keywords: High enthalpy flows · atmospheric entry · state-to-state kinetics.

It is well known that inside the shock and boundary layer of a body entering planetary atmospheres, thermal and chemical non-equilibrium establishes. The MT approach is commonly used to model this phenomenon, adding the species source terms in the mass continuity equations and the internal contribution to the energy equation. The thermal non-equilibrium is accounted for by adding an equation for the evolution of the internal energy (temperature, T_v) and considering the rate coefficients depending on both T_v and T (the gas translational temperature). The Park model [1] is the most used approximation of the MT approach, considering the Landau-Teller equation for the vibrational temperature relaxation, while the chemical rate coefficients are Arrhenius function of an effective temperature (T_{eff}) calculated as $T_{eff} = T^{\gamma} T_v^{1-\gamma}$ where the coefficient γ accounts for the different weight of internal and translational degrees of freedom in each reaction.

In recent years, the StS approach is diffusing to model the non-equilibrium in high enthalpy flows [2]. It consists in adding a mass continuity equation for relevant internal levels of the species, considered as pseudo–species. In this context the internal level distribution is calculated making unnecessary the definition of an internal temperatures. The chemical rates, including also those for internal energy exchange processes, are a function of the temperature and of the level indexes of the species involved in the reaction. This model, borrowed from plasma chemistry [3], are applied to the vibrational kinetics of diatomic molecules [4] even if it can be easily extended to atomic and molecular electronic states [5]. The StS model has been applied only in 1D simulations, because of the large

dimension of the chemical problem. However the implementation of GPU's in the calculations allowed to extend the model to 2D calculations of high enthalpy flows around blunt [6] and sharp [8] bodies. Results show that in both cases there are differences between the MT and StS kinetics as can be observed in Fig. 1, and in the case of the flow around a sphere an excellent agreement with the experimental stand-off distance measured by Nonaka [7].

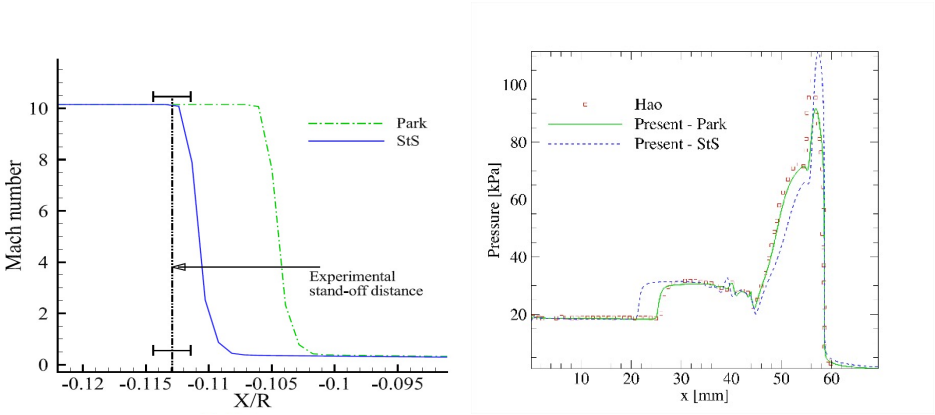

Fig. 1. *Left*: Mach number along the stagnation line of the flow around a sphere [6]: comparison among Park, StS and experimental [7] stand-off distance.
Right - Pressure along the surface of supersonic flow around a double wedge [8]: Comparison between Park, StS and Hao calculations [9].

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