Modelling hypersonic flows in thermochemical nonequilibrium with Adaptive Mesh Refinement

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Adequate resolution of the flow field is vital to ensure that simulations are accurate, but an overly resolved mesh can lead to excessive computational times. Adaptive Mesh Refinement (AMR) algorithms are able to balance these two constraints by increasing the resolution only where it is needed. In this work, computations of hypersonic flows using a block-Structured Adaptive Mesh Refinement (SAMR) solver are presented. An SAMR solver has been coupled to the Mutation++ thermochemical library to enable high resolution simulations of flows in thermochemical nonequilibrium.

The computational framework AMROC (Adaptive Mesh Refinement in Object-oriented C++), implements the Cartesian SAMR algorithm of Berger and Colella on parallel computers with distributed memory, where non-Cartesian geometries are considered with an embedded boundary approach [2]. In previous work [1], a single-temperature TVD-MUSCL scheme for simulating reacting mixtures of thermally perfect gases on highly adaptive meshes had been developed.

In the present work, an extended version of that solver has been coupled to the Mutation++ library [3] in order to model flows in thermochemical nonequilibrium. Park's two-temperature model is used to model the thermodynamic nonequilibrium, and the thermodynamic properties of each species is calculated using the species' partition function. The forward reaction rates are calculated using an Arrhenius equation, modified for the two-temperature model, and the equilibrium constant is determined as a function of the change in Gibbs' free energy.

The results of various high enthalpy flow computations are presented. A simulation of inviscid flow over a double wedge demonstrates the ability of the SAMR to effectively resolve discontinuities and shock-shock interactions. Two-dimensional axisymmetric computations of shock stand-off distance around a sphere in hypersonic flow are compared with experimental data, showing good agreement. A comparison between a mapped mesh computation and a computation using the ghost fluid method is given, showing good agreement.

References

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