Development of a new high-performance code for hypersonic flow simulations

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Abstract

In this work, a new object-oriented software framework that supports the development of flexible multi-physics and multi-numerics parallel applications that operates on unstructured grids is briefly described. The software employs the object-oriented facilities provided by the Fortran 2003 standard, and the design clearly separates the parallel management of the grid topology and the data attached to the grid from the application code.

The system is applied to the development of a high-performance finite volume code based on dimension-independent unstructured grids composed of arbitrary polyhedra and oriented to the numerical solution of the compressible Navier-Stokes equations, targeting steady state hypersonic air flow scenarios. The solver is capable of dealing both with chemical and thermal non-equilibrium effects. Upwind flux vector splitting methods of the AUSM-family are employed to provide both robust shock-capturing and accurate boundary layer and heat transfer resolution capabilities. Second-order accuracy is achieved through linear reconstruction of the solution, employing the Venkatakrishnan's limiter to assure monotonicity properties. Multi-component transport modeling of viscosity, conductivity and molecular diffusion are briefly discussed. A fully-coupled implicit method is employed to advance the solution in time, and the linear system in each time step is solved through GMRES iterative methods, employing third-party libraries. Both a 5-species (N, O, N_2, O_2, NO) and an 11-species ($N, O, N_2, O_2, N^+, O^+, N_2^+, O_2^+, e^-$) air kinetic models are implemented. Thermal non-equilibrium effects are included employing a two temperature model, in which it is assumed that the translational and rotational energy modes are in equilibrium at the translational temperature, and the vibrational, electronic and electron translational energy modes are in equilibrium at the vibrational temperature. Benchmark cases of the steady state thermo-chemical non-equilibrium air flow over blunt bodies and a double-cone configuration are presented in order to test and illustrate the robustness and accuracy of the developed code. Finally, scaling tests oriented to study the performance of the solver in distributed systems are presented and discussed.

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