NUMERICAL SIMULATION OF HYPERSONIC RE-ENTRY FLOWS IN CHEMICAL EQUILIBRIUM AND NONEQUILIBRIUM USING AN OBJECT ORIENTED SOLVER

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Hypersonic applications are becoming increasingly popular. The area of hypersonic aerothermodynamics encompasses fields such as the development of re-entry vehicles, atmospheric hypersonic vehicles and scramjet engines. Because of the high-risk high-cost nature of this technology, many smaller projects exist currently to form an intermediate step before the development of realistically sized hypersonic vehicles and applications. Since cost-efficiency is essential in this area it is important to be able to model as many phenomena as possible before anything is built.

The aim of this project is to provide an alternative way of modeling hypersonic flows using the assumption of *Local Thermodynamic Equilibrium* (LTE) with *Variable Elemental Fractions* (VEF). It is well known that the flowfield during a re-entry is highly dominated by thermal and chemical *nonequilibrium* (NEQ) effects. However, at lower altitudes, where the Mach number decreases and the pressure increases the assumption of LTE may hold. One objective of the present project is to verify this proposition. In some circumstances the heat peak load on a vehicle falls into this regime as well. The aim of this method is to be able to compute the flowfield around a hypersonic configuration in a cost-efficient way and without the uncertainties of full NEQ modeling, even at the heat peak point of the re-entry trajectory - which is of particular interest for designers of heat shields. For validation purposes and to further extend the possibilities of hypersonic flow computations, a *chemical nonequilibrium* (CNEQ) model is also implemented. *Thermal equilibrium* is assumed in both descriptions (LTE-VEF, CNEQ).

The codes are implemented into COOLFluiD (Computational Object Oriented Library for Fluid Dynamics). This is an object oriented framework written in C++ to support multi-physics computations on unstructured grids and parallel computers, particularly in the field of fluid dynamics. An LTE model using *Fixed Elemental Fractions* (FEF) was already available in COOLFluiD. The LTE-VEF model solves additional advection-diffusion equations for the elemental fractions in the form of elemental continuity equations, while the CNEQ model has additional equations for the chemical composition (species) of the mixture. The implementation has been made for 2D and 3D, however for the moment, the 3D simulations have been applied to inviscid flow only. A limitation is that the codes are currently applicable only for neutral mixtures of gases.

Simulations have been carried out on a numerous testcases and comparison of the results with LTE-FEF (COOLFluiD) and NEQ codes (COSMIC) has been made. The effect of elemental diffusion on the heat flux to hypersonic bodies is examined in details.

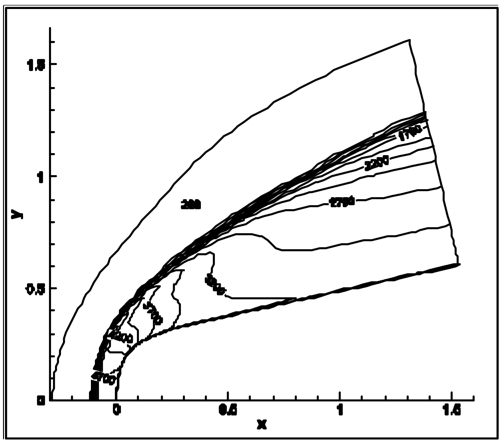

Figure 1: Temperature distribution [K] around a 2D KHEOPS section, M=14, CNEQ