Preface

The book presents recent theoretical and experimental results achieved in Russia in the field of aerothermodynamics of hypersonic flows over complex configurations. These results include analysis of gas flows over the space shuttle "Buran", various aircraft configurations and interplanetary vehicles. The entire problem of hypersonic aerothermodynamics is split into two closely linked parts: gas dynamics itself and physical models.

The gas dynamic models, which are considered in the book, include the Navier-Stokes equations along with their asymptotic simplifications at very high Reynolds numbers such as the Thin Viscous Shock Layer (TVSL) equations and Parabolised Navier-Stokes (PNS) equations. The latter equations are written down in special variables to obtain locally self-similar solutions that have sufficient accuracy with regards to the friction and heat transfer coefficients on windward sides of hypersonic aircrafts. An efficient iterative method is described to solve these reduced Navier-Stokes equations. It requires only a few iterations to reach the stationary solution, if it exists, in the case of flows with a predominant direction.

If non-equilibrium chemical reactions are to be taken into account for multicomponent gas mixtures of partially ionized gases, an exact formulation of heat and mass transfer can be important in the case of different binary diffusion coefficients. In the book it is formulated via the Stefan-Maxwell relations. In contrast to the conventional formulation "fluxes via thermodynamic forces", there relations consider "forces vs fluxes". This allows us to avoid double inversion of matrices of order $N*\xi$, where N is the number of component, ξ is the number of terms retained in the Sonin polynomials that are used in the Chapman-Enskog method. The obtained formula provides the exact relation for the thermodynamic forces vs the fluxes. It is a foundation for other very useful results such as simpler transport coefficients. In the case of equilibrium chemical reactions these transport coefficients are written out explicitly. To describe hypersonic high temperature flows, the full set of governing equations is formulated for multicomponent gas mixtures with the account of chemical reactions, multitemperature effects and radiation. This system of equations is to be completed by boundary conditions.

The boundary conditions at the wall take into account the effects of slip and temperature jump for the velocity and temperature, and catalytic activity for the species. A new phenomenological description of heterogenic catalytic processes is given in application to low catalytic surfaces of space vehicles in the Earth and Mars atmospheres. The coefficient of catalytic activity for a thermoprotection surface can be successfully calculated using direct numerical simulation methods from molecular dynamics.

It is well known that the system of Navier-Stokes equations with nonequilibrium chemical reactions is stiff if some reactions are close to equilibrium (the problem of partial equilibrium). To overcome such a problem, a new efficient method is described. In this method, one or two "slow" variables are introduced in such a way that they represent a linear combination of fraction of species as well as their diffusion fluxes. As a result, the stiff diffusion equations can be replaced by the condition of the Debye chemical equilibrium. The provided test cases confirm high accuracy of the model in application to hypersonic flows over space vehicles in the Earth and Mars atmospheres. Another series of test cases is related to the interaction of plasma flow with the thermoprotection surface. It is numerically and experimentally studied in the conditions of a discharge plasmatron.

Various computational experiments carried out for real space vehicle configurations allowed us to identify the regimes at which the viscous-inviscous interaction is important for the prediction of heat fluxes. It is also shown that the heat fluxes on a leeward side of space vehicle and the stagnation point can be comparable due to flow tubulization. Ablation effects are also considered in detail in application to composite silicon-based materials.

Rarefaction regimes are considered on the basis of continuum medium models. It is demonstrated that the TSVL model is capable of providing good enough prediction for the heat transfer and friction coefficients while the Navier-Stokes equations fail. This counterintuitive result is verified numerically and analytically at low Reynolds numbers and explained.

The final chapter of the book is devoted to the description of a novel domain decomposition approach for near-wall turbulence modelling. The main idea is that the boundary conditions are transferred from the wall to an interface boundary. Then, the problem needs to be solved in the outer domain. The solution in the inner domain can be obtained afterwards.

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