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CHEMICAL NON EQUILIBRIUM SIMULATIONS OF HYPERSONIC FLIGHTS IN CARBON DIOXIDE-NITROGEN ATMOSPHERES USING A COUPLED EULER-SECOND-ORDER BOUNDARY LAYER METHOD

Abstract

Re – entry flights in carbon dioxide – nitrogen atmospheres such as Mars and Venus became more and more the focal point of interest in the research community lately. During these re – entry flights a wide range of density and pressure variations are passed at hypersonic velocities, generating a high temperature flow field behind the bow shock. Due to the fact of this high temperature flow field the constituent chemical species inside this shock layer undergo several significant chemical reactions for example dissociation. With respect to the typical atmospherical low density / low pressure regions which are passed during re – entry flights, dissociation occurs at a wide range, starting at high altitudes affecting aspects like surface chemistry or wall heat fluxes significant. Therefore it is important to generate accurate thermodynamic, kinetic and transport models with a chemical non equilibrium approach, where the conservation equations for momentum, total energy and balance equations for each species are solved in the flow field.

In this work a 47 reaction, 8 species model will be implemented in a coupled second – order Euler – boundary layer non equilibrium method using a 4^{th} order finite difference method accounting for CO_2, CO, N_2, O_2, NO, C, N and O as relevant species. Several hypersonic flight simulations at different velocities and different altitudes will be made and compared to available equilibrium simulations in analogous configurations with the same numerical method. As a test configuration a hyperbola / hyperboloid is used.

Furthermore the approach made here is less general than solving the Navier – Stokes equations. It solves the inviscid Euler equations first, providing the boundary conditions for the viscous boundary layer equations, which are solved with second order accuracy, accounting for phenomena like entropy layer swallowing, curvature effects etc. Subsequently, both solutions are coupled. With respect to the fact that the Navier – Stokes equations are the most comprehensive equations for continuum fluid mechanics, but still the most computational expensive ones, this approach generates results in the same order of accuracy in its domain of application with less computational effort. It has proved its applicability for blunt re - entry bodies at high angles of attack and medium to low altitudes as long as there is no strong interaction between the viscous boundary layer flow and the inviscid Euler flow.