Analysis of Non-Equilibrium, Hypersonic Blunt Body Flow with the Local Similarity Method

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Abstract: A method for the calculation of the stagnation streamline quantities and the stagnation point heat transfer in hypersonic flows about spheres or cylinders is suggested, which is based on the local similarity of the flow field. Comparisons with two–dimensional Euler and Navier–Stokes calculations and experiments are presented, which include perfect gas flows and non–equilibrium air flows.

Key words: Non–Equilibrium, Stagnation Streamline, Local Similarity

1. Introduction

A spacecraft entering the atmosphere generates a strong bow shock, that leads to the excitation of molecule vibration and dissociation. A non–equilibrium flow prevails, if the relaxation times of these processes are of the order of the fluid dynamic time scale. Such flows are described mathematically by the conservation laws and additional balance equations for the component densities and the vibrational energies. Physical models provide relations for the chemical production rates, the rates of vibrational energy transfer and the molecular fluxes. Flows about spheres or cylinders with high aspect ratio are suitable for the investigation and validation of the gas physical models. The stagnation streamline quantities and the stagnation point heat flux are of major interest in this context. We therefore consider a method for the fast calculation of these quantities.

2. The local similarity method

Stagnation streamline quantities are usually obtained from an asymptotic steady state solution of the two–dimensional, unsteady flow problem. However, as two–dimensional hypersonic flows about spheres or cylinders exhibit an approximate local similarity in the stagnation streamline area, the number of independent spatial variables can be reduced from two to one (Kao 1964). The dimensionally reduced Navier–Stokes equations (DRNSE) are derived from the Navier–Stokes equations in spherical or cylindrical co–ordinates. In our empirical approach the