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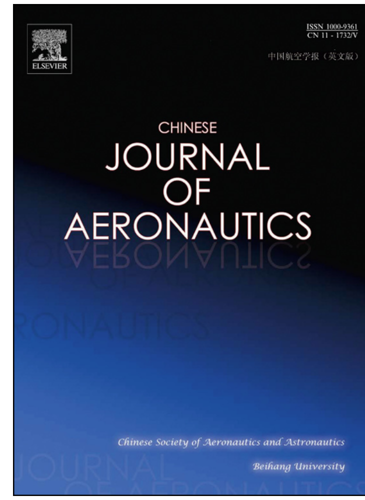

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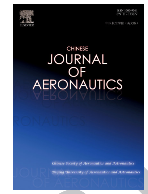

A quasi-one-dimensional model for hypersonic reactive flow along the stagnation streamline

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Abstract

This study proposes a quasi-one-dimensional model to predict the chemical non-equilibrium flow along the stagnation streamline of hypersonic flow past a blunt body. The model solves reduced equations along the stagnation streamline and predicts nearly identical results as the numerical solution of the full-field Navier-Stokes equations. The high efficiency of this model makes it useful to investigate the overall quantitative behavior of related physical-chemical phenomena. In this paper two important properties of hypersonic flow, shock stand-off distance and oxygen dissociation, are studied using the quasi-one-dimensional model with the ideal dissociating gas model. It is found that the shock stand-off distance is affected by both chemical and thermal non-equilibrium. The shock stand-off distance will increase when the flow conditions are changed from equilibrium to non-equilibrium, because the average density of the shock-compressed gas will decrease as a result of the increase of translational energy. For oxygen dissociation, the maximum value of its dissociation degree along the stagnation line varies with the flight altitude. It is increased at first and decreased thereafter with the altitude, which is due to the combination effect of the equilibrium shift and chemical non-equilibrium relaxation. The overall variation of the maximum dissociation is then plotted in the speed and altitude coordinates as a reference for engineering application.

Keywords: Quasi-one-dimensional model; Hypersonic; Non-equilibrium; Stagnation flow; Shock stand-off distance

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1. Introduction

It is well-known that a vehicle traveling at hypersonic speed will excite the air to a high temperature and change its thermochemical properties. For instance, Hansen and Heims [1] made an earlier review of the thermodynamic, transport and chemical reaction rate properties of high temperature air and summarized the air chemistry near stagnation region in the coordinate system of speed and altitude. Gupta et al. [2] presented a later review for an 11-species air model and added lines in the plot to specify the non-equilibrium regions, which is a very rough estimation since the previous equilibrium air chemistry was still adopted. The detailed aerothermodynamics, however, has not been fully recognized although great efforts have been done since then. There are still more unsolved problems than solved problems in hypersonic aerothermodynamics according to Park [3] in a recent review article. Among twelve unsolved problems, nine problems are related to thermochemical non-equilibrium processes. Park suggested to improve non-equilibrium models and to study thermochemical phenomena for gas mixtures other than air in the future.

If non-equilibrium models are prescribed for the surrounding flow during hypersonic flight, there should be no significant technical difficulties for latest computational fluid dynamics (CFD) to simulate. Model complexity and mesh resolution[4], however, would make CFD simulations time-consuming, which is not suitable for parameter studies on thermochemi-