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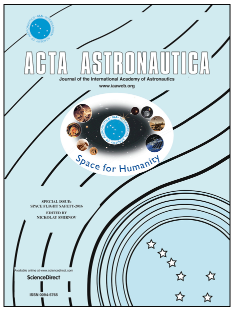

Surface thermochemical effects on TPS-coupled aerothermodynamics in hypersonic Martian gas flow

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Surface Thermochemical Effects on TPS-Coupled Aerothermodynamics in Hypersonic Martian Gas Flow

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Abstract:

This paper deals with the surface thermochemical effects on TPS-coupled aerothermodynamics in hypersonic Martian gas flow. An interface condition with finite-rate thermochemistry was established to balance the three-dimensional Navier-Stokes solver and TPS thermal response solver, and a series of coupled simulations of chemical non-equilibrium aerothermodynamics and structure heat transfer with various surface catalycities were performed for hypersonic Mars entries. The analysis of surface thermochemistry reveals that the surface chemical reactions have great contribution to aerodynamic heating, and the temperature-dependence of finite-rate catalysis highly influences the evolution of the coupling aerodynamic heating in the coupling process. For fixed free stream parameters with proper catalytic excitation energy, a "leap" phenomenon of the TPS-coupled heat flux with the coupling time appears in the initial stage of the coupling process, due to the strong thermochemical effects on the TPS surface.

Key words:

Aerothermodynamics; Thermochemical effects; Coupling; Hypersonic; Martian gas; "Leap" phenomenon

1 Introduction

Mars entry activities have been the hot spot in the field of deep space exploration in the recent years. After a long-duration inter-planet flight, the Mars entry vehicle will traverse the entire Martian atmosphere at extremely high speed before landing on the Mars surface [1]. Several probes or rovers have been landed on the Mars surface ever since 1970s [2], and some new Mars entry programs or concepts were put forward recently [3]-[4]. The first Chinese Mars orbital and entry mission is scheduled to be launched in 2020 [5].

Although there are several successful Mars entry missions up to now, these missions still uncovered some new aerodynamic and aerothermodynamic issues during their entry, descent and landing stage. Severe and complex aerodynamic heating environment with considerable uncertainties for deep space vehicles introduces great challenges to the thermal protection system (TPS) design [6]. Therefore, critical light-weight TPS structure is required to resist such great aerothermal load from the hypersonic non-equilibrium flow, especially for Mars entry missions with quite large planetary flight uncertainties [7]. Reliable and precise prediction of aerothermodynamics and thermal response is essential for the TPS design of future Mars exploration vehicles [8].

Surface thermochemistry describes the chemical aerodynamic heating enhanced by the TPS materials, including surface catalysis and ablation reactions. The transfer of the chemical energy on the gas-solid interface, however, depends greatly on how the multiple reaction channels are assigned and the proportion of each channel, which directly influences the consequent