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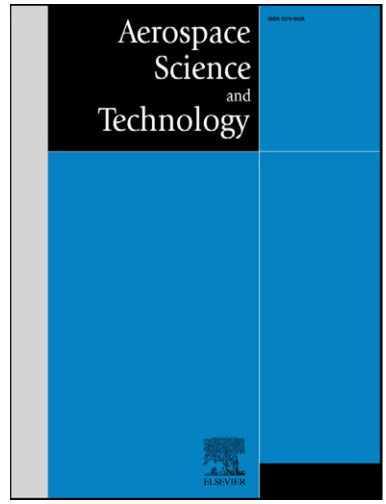

Variable transpiration cooling for the thermal management of reusable hypersonic vehicles

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Variable Transpiration Cooling for the Thermal Management of Reusable Hypersonic Vehicles

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The overall aerodynamic performance of every flying vehicle is strongly dependent on near-wall effects. In the hypersonic regime, the viscous dissipation of the high-enthalpy flow over the vehicle is responsible for the generation of surface temperatures and heat fluxes that can easily exceed the thermo-mechanical limits of current materials. Based on these considerations, it is important to understand the physics that characterize the boundary layer and its interaction with the vehicle's surface in order to simulate its behavior for different surface parameters such as the type of material, surface manufacturing, surface coating, wall geometry, mass exchanges, etc. The work presented in this paper is focused on the mass exchanges at the surface, and investigates the cooling effectiveness of the proposed variable transpiration cooling concept for the case of hypersonic laminar boundary layers on a flat plate. A reduced order model that captures the relevant physics has been developed and implemented in a code that solves the Navier-Stokes equations written for stationary, non-reacting, hypersonic laminar boundary layers and neglecting the radiative thermal exchange. The code uses a coupled solution of Self-Similar Method and Difference-Differential Method assuming a unitary Prandtl and Lewis number. Selected distributions of the coolant (air) transversal velocity at the wall have been considered to simulate the variable transpiration. The analysis reveals that the constant-linear wall velocity distribution minimizes the wall heat flux (for a specified wall temperature) along the flat plate if the total coolant mass-flow rate is kept constant. In addition, the saw-tooth wall velocity distribution allows for a reduction of nearly *37%* of the required coolant mass with respect to the other cases. These results highlight the potential thermal-management implications of this concept applied to hypersonic vehicles. The comparison between the computationally inexpensive reduced order code (AERO-Code) and the high-fidelity Computational Fluid Dynamics code GASP shows similar qualitative and quantitative results on the heat fluxes and shear stresses prediction.

Keywords: thermal management, hypersonic vehicle, thermal protection system, active cooling, transpiration cooling

Nomenclature

A_{TOT}	=	surface exposed to the flow, m^2
BC	=	boundary condition
BL	=	boundary layer