Compressibility Effects on the Aerodynamic Surface Quantities of Hypersonic Gap Flows

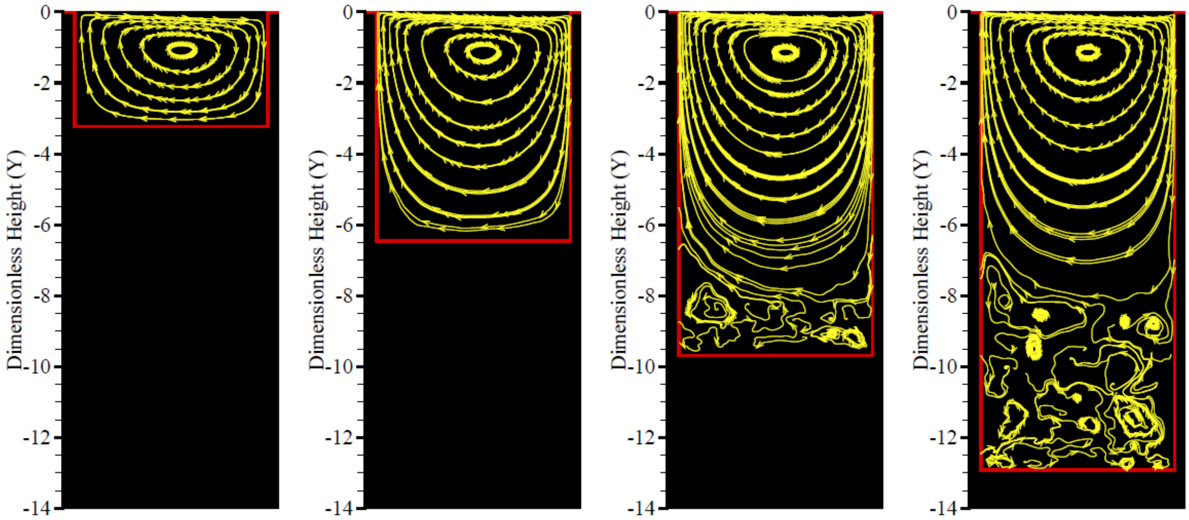
Luis T. L. C. Paolicchi and Wilson F. N. Santos•

The thermal protection systems of vehicles like the space shuttle orbiter or crew rescue vehicle X-38 require gaps between the used protection elements to account for thermal expansion. For the optimized design of gaps and protection elements, it is necessary to predict the flow conditions and thermal loads as accurate as possible. The flow in the gap is complex because of staggered gap configuration, radiation cooling, transient flow, etc. In the case of reentry vehicles, the boundary layer transition prediction is a requirement to define the thermal protection system. This protection is usually designed as an assembly of tiles. The gaps between the tiles may modify the boundary layer state and eventually promote transition, inducing higher temperature levels than expected. For the particular case of gaps, some experimental studies have been conducted in order to understand the physical aspects of a hypersonic flow past to this type of surface discontinuities. In general, the major interest in these studies has gone into considering laminar or turbulent flow in the continuum flow regime. Nevertheless, there is little understanding of the physical aspects of a hypersonic flow over gaps related to the severe aerothermodynamic environment associated to a reentry vehicle.

In this fashion, Paolicchi and Santos [1] have studied gaps situated in a rarefied hypersonic flow by employing the Direct Simulation Monte Carlo (DSMC) method. The work was motivated by the interest in investigating the length-to-depth (L/H) ratio effects on the flowfield structure. The primary emphasis was to examine the behavior of the primary properties, such as velocity, density, pressure and temperature, due to changes on the gap L/H ratio. The analysis showed that the gap flow behavior in the transition flow regime differs from that found in the continuum flow regime, for the conditions investigated. It was found only one vortex for the *L/H* ratio of 1, 1/2, 1/3 and 1/4, as shown in the figure below. Conversely, in the continuum flow regime, the number of vortices inside the gap is approximately given by the amount H/L.

Having established a physical picture of the flowfield structure in a gap, the current study expands on the results presented in the previous analysis [1] by investigating the effects of the compressibility as well as the L/H ratio on the aerodynamic surface quantities. In this manner, the purpose of the present account is to investigate numerically the sensitivity of the heat transfer, pressure and skin friction coefficients due to changes on the gap L/H ratio and on the freestream Mach number in the transition flow regime. In the present account, L/H ratio will change from 1 to 1/4, with L of 3 mm. The freestream Mach number will be 5, 15 and 25. The focus of the present study is the low-density region in the upper atmosphere. At high altitudes, and therefore, low density, the molecular collision rate is low and the energy exchange occurs under non-equilibrium conditions. In such a circumstance, the degree of molecular non-equilibrium is such that the Navier-Stokes equations are inappropriate. Therefore, the DSMC method will be employed to calculate the hypersonic two-dimensional flow on the gaps.

- National Institute for Space Research (INPE)
  Combustion and Propulsion Laboratory (LCP)
  Rod. Presidente Dutra, km40
  Cachoeira Paulista-SP 12630-000
  Brazil
  wilson@lcp.inpe.br



(a) $L/H = 1$ (b) $L/H = 1/2$ (c) $L/H = 1/3$ (d) $L/H = 1/4$

[1] Paolicchi, L. T. L. C., and Santos, W. F. N., "Direct Simulation Calculations of Rarefied Hypersonic Gap Flow", *3rd Southern Conference on Computational Modeling*, Rio Grande, RS, Brazil, Nov 23–25, 2009.