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COMPRESSIBILITY EFFECTS ON COMBINED GAP/STEP GEOMETRIES AT RAREFIED HYPERSONIC FLOW

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It is generally recognized that the physical phenomena related to the problem of separation are very important in the design of hypersonic configurations. When separation occurs in high Mach number flows, changes in pressure distribution and heat transfer rate may have catastrophic effects in the vehicle. The presence of hot spots at separation and reattachment points changes the characteristics of the flow over the vehicle and can cause failure in the thermal protection system, as was evidenced by the tragic loss of Space Shuttle Columbia in 2003. In general, separation occurs due to the interaction of external flows with various desired or undesired design features present on the vehicle surface, such as protuberances, notches, cavities, gaps, or steps.

In the current literature, there is a rather extensive studies dealing with flows on cavities, gaps, and steps. In general, these research studies have been conducted in order to understand, among others, the physical aspects of a laminar or turbulent boundary layer in a subsonic, supersonic or hypersonic flow past to these types of discontinuity, characterized by a sudden change on the surface slope. The major interest in these research studies has gone into considering laminar or turbulent flow in the continuum flow regime. However, there is little understanding of the physical aspects of rarefied hypersonic flows past to these discontinuities related to the severe aerothermodynamic environment associated with a reentry vehicle.

In this scenario, Leite and Santos [1] have investigated forward-facing steps situated in a rarefied hypersonic flow by employing the Direct Simulation Monte Carlo (DSMC) method. The studies were motivated by the interest in investigating the frontal-face height effect on the flowfield structure and on the aerodynamic surface properties in the transition flow regime, i.e., between the continuum flow and the free collision flow regime.

The computational results showed that the step-height changes contributed to significant modifications in the flowfield structure ahead the step.

In addition, Paolicchi and Santos [2] have studied gaps situated in a rarefied hypersonic flow by employing the 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 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. Conversely, in the continuum flow regime, the number of vortices inside the gap is approximately given by the amount H/L.

In the present account, effort is directed to expand the previous studies [1, 2] by investigating another surface discontinuity defined by the combination of a step and a gap. This type of discontinuity, a combined gap/step, may occur in the windward surface of the space shuttle configuration. The windward surface is composed by a large number of thermal protection tiles. However, a misalignment between individual tiles may occur. Therefore, the misaligned tiles may constitute in a potential source in a heat flux and pressure rise on the surface or even though in a premature transition from laminar to turbulent flow. In this fashion, the primary goal is to provide a comprehensive description of the compressibility effects on the flowfield structure. Freestream flow conditions employed in the present calculations are those given in the previous work [1, 2], and represent those experienced by a reentry vehicle at an altitude of 70 km with freestream Mach number of 5, 15, and 25.

The focus of the present study is the low-density region in the upper atmosphere, where numerical gaskinetic procedures are available to simulate hypersonic flows. High-speed flows under low-density conditions deviate from a perfect gas behavior because of the excitation of rotational and vibrational modes. At high altitudes, and therefore, low density, the molecular collision rate is low and the energy exchange occurs under non-equilibrium conditions. In this framework, 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 combined gap/step geometry.

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