Aerodynamics of Two Interfering Simple-Shape Bodies in Hypersonic Rarefied-Gas Flows

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ABSTRACT

Hypersonic rarefied-gas flows near two side-by-side plates and cylinders, a plate and cylinder over a plane surface, and a plate behind a cylinder in argon have been studied numerically by the direct simulation Monte-Carlo technique\textsuperscript{1-4} under the transition rarefied-gas-flow regime conditions at Knudsen numbers, \( Kn_{\infty, L} \) from 0.024 to 1.8. Strong influences of the geometrical factor (the ratio of a distance between bodies to a body length, \( 2H/L \)) and the Knudsen number on the flow structure about the bodies (the shape of shock waves, the configuration of subsonic flow zones) and on skin friction, pressure distribution, lift and drag have been found.

The flow pattern and shock-wave shapes are significantly different for small and large geometric ratios. At \( H/L = 0.5 \), the disturbances interact in the vicinity of the symmetry plane, creating the Mach normal shock wave and a wide subsonic area, which occupies the whole “throat” area between two side-by-side plates. This phenomenon produces significant repulsive lift force. A non-monotonous dependency of lift and drag from values of the Knudsen number has been found for different geometric factors (see Fig. 1). The rarefaction effects on the lift force are significant at all considered values of the geometrical factor (1.25 \( \geq H/L \geq 0.25 \)). At small factors, the repulsive lift force on side-by-side plates becomes significant with the lift-drag ratio of 1.6 in near-continuum flow regime and significantly reduces (up to 0.4) in the near-free-molecular flow.

In the case of two side-by-side cylinders at the small ratio parameters, \( H/R \leq 2 \), the front shock-wave shape becomes normal, and the front stagnation points (180\(^\circ\)) relocate from the cylinder front zone towards the “throat” area (see Fig. 2). This phenomenon\textsuperscript{5} affects the drag, pressure and skin-friction distributions along a cylinder and produces significant repulsive lift force with \( Cy/Cx = 0.35 \). The geometrical factor becomes insignificant on the drag both under continuum flow regime conditions and in free-molecule flow at \( H/R \geq 4 \).
FIGURE 2. Skin-friction Coefficient along the Side-by-Side Cylinder Surface at $Kn_{aL} = 0.1$ at $M_\infty = 10$.

In the case of a plate over a surface, the subsonic area between the plane surfaces becomes much wider than in the case of two side-by-side plates. This effect results in the significant increase in the repulsive lift force at $2H/L \geq 1$ in the considered case (see Fig. 3, $Kn_{aL} = 0.071$ and $M_\infty = 10$).

FIGURE 3. Total Drag and Lift Coefficients of a Plate over a Surface vs. Coefficients of Side-by-Side Plates.

Finally, the rarefied-gas flow about a blunt plate located in the wake of a cylindrical wire has been numerically studied. At the strong interaction regime\textsuperscript{3}, the induced wake flow in front of the plate reduces the strength of the shock wave and results in reducing the plate drag up to 8.3% and friction – up to 5%.

REFERENCES