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## ABSTRACT:

### Drag Reduction Mechanism of Micro-Blowing System in a Supersonic Turbulent Boundary Layer

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Micro-blowing technology has demonstrated potential for efficient drag reduction in supersonic turbulent boundary layers. To investigate the underlying mechanisms, direct numerical simulations were conducted to examine the effects of single-hole[1], dual-hole, and multi-hole[2] micro-blowing on supersonic turbulent boundary layers.

For the single-hole configuration, results reveal a dual-regime drag reduction mechanism: upstream reduction is driven by adverse pressure gradients, while downstream reduction is dominated by mean convection effects. The micro-blowing system establishes a three-layer shear interaction system (“wall–air film–mainstream”) downstream through the formation of a low-speed air film, effectively reducing near-wall skin friction and turbulent fluctuations.

Preliminary studies on dual-hole micro-blowing indicate that spanwise interaction enhances drag reduction, whereas streamwise interaction tends to decrease drag reduction effectiveness.

In the multi-hole configuration, micro-blowing achieving a total drag reduction of 17.92% within the control region. Skin friction decomposition shows that drag variations are dominated by pressure gradients and convection: adverse pressure gradients reduce drag upstream and within the control region, while favorable pressure gradients and convection influence near-downstream drag. Further downstream, even as turbulent equilibrium is reestablished, drag reduction persists due to boundary layer thickening and the associated reduction in velocity gradients.

[1] P.J. Zhao, X.S. Wu and Y.X. Zhao, Chinese Journal of Aeronautics, 103830 (2025).

[2] P.J. Zhao, X.S. Wu and Y.X. Zhao, Physics of Fluids, 37, 105104 (2025).