Effects of wall heat transfer on the transport of Reynolds shear stress and turbulent heat flux in compressible turbulent boundary layers

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The characterization of compressible turbulent boundary layers (TBLs) remains an active research area in aerodynamics and thermodynamics. In particular under the isothermal wall condition, the effect of wall heat transfer is found to change the velocity dilatation significantly and cause variations of TBL behaviour to a greater extent than the Mach-number influences[1]. This research investigates how the mean wall heat transfer and its fluctuation intensity influence the distribution and transport of Reynolds shear stress and turbulent heat flux across the boundary layer.

Following our previous study on the framework of energy exchange in compressible turbulent flows[2], a sound-speed-like variable ($\phi \propto c$) is first introduced, to derive the transport equation of turbulent heat flux. TBLs at $M_\infty = 5.86$ and $Re_\tau = 420$ are considered via direct numerical simulation, and two wall thermal conditions, with $T_w/T_r = 0.76$ ($cold1$) and 0.25 ($cold2$) to represent weak and strong wall-cooling intensity, are studied. The contribution of wall-heat-transfer fluctuations (q'_w) to the distribution of Reynolds shear stress and turbulent heat flux, as well as their budgets including the production, pressure work and turbulent transport, is examined. Figure 1(a) shows the probability density function (p.d.f.) of the q'_w in both cases, with the coloured tails representing the extreme 2% positive or negative q'_w-events. With strong wall cooling, the negative q'_w-events are observed to be stronger in intensity but fewer in number. Conditional average of Reynolds shear stress on the extreme positive and negative q'_w-events is plotted in figure 1(b). Obvious differences are seen in the near-wall region, with positive events associated with ejections and negative events with sweep motions. Joint p.d.f.s of velocity/temperature perturbations and q'_w and the conditional profiles of mean velocity/temperature will also be examined, to investigate the underlying mechanisms of wall-heat-transfer effects on the budgets.

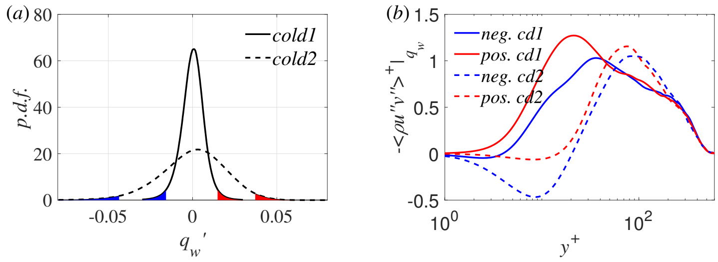

Figure 1: (a) The probability density function of the wall-heat-transfer fluctuations. (b) Contribution of positive and negative q'_w-events to the distribution of Reynolds shear stress.

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[1]Wenzel et al., *J. Fluid Mech.* **930**, A1 (2022).
[2]Fan et al., *Phys. Rev. Fluids* **7**, L092601 (2022).