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Effect of wall heating on turbulent boundary layers with temperature-dependent viscosity.
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Summary: Direct numerical simulations (DNS) of turbulent boundary layers over isothermally heated walls were performed, and the effect of viscosity stratification on the turbulence statistics and skin friction were investigated. An empirical relation for temperature-dependent viscosity for water was adopted. Based on the free-stream temperature (30°C), two wall temperatures (70°C and 99°C) were selected. In the heated flows, the turbulence energy diminishes in the buffer layer, but increases near the wall. The reduction in turbulence kinetic energy in the buffer layer is accompanied by smaller levels of Reynolds shear stresses and, hence, weaker turbulence production. The enhanced turbulence energy near the wall is attributed to enhanced transfer of energy via additional diffusion-like terms due to the viscosity stratification. Despite the lower fluid viscosity near the wall, dissipation is also increased owing to the augmented near-wall fine-scale motion. Wall heating results in reduction in the skin-friction coefficient by up to 26%. An evaluation of the different contributions to the skin friction demonstrates that drag reduction is primarily due to the changes in the Reynolds shear stresses across the boundary layer. Quadrant and octant analyses showed that ejections (Q2) and sweeps (Q4) are significantly reduced, a result further supported by an examination of outer vortical structures from linear stochastic estimation of the ejection events and spanwise vortices.

MSC:

76F40 Turbulent boundary layers
80A20 Heat and mass transfer, heat flow (MSC2010)

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turbulent boundary layers; turbulent flows

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