Non-monotonic heat flux in mixed vertical convection

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Understanding what determines the heat flux due to convective boundary layers at steeply sloped walls is important to a wide range of industrial and environmental applications. A useful canonical system for studying such boundary layers is the vertical convection (VC) setup, where we study the flow between two differentially heated vertical plates. Buoyancy drives the flow up one wall and down the other. For sufficiently strong thermal driving or sufficiently large domains, characterised by the Rayleigh number Ra, the flow becomes turbulent.

However, in many applications an ambient flow is also present, which introduces an additional control parameter to the problem: the Reynolds number Re_b of the ambient flow. To investigate how a mean horizontal flow impacts the heat flux in the VC system, we perform direct numerical simulations of mixed vertical convection. In this system, we impose a mean volume flux across the plates as shown in the scematic of Fig. 1(a). An instantaneous snapshot of the temperature field and wall-normal heat flux is presented in Fig. 1(b), highlighting the tilted structures at the wall.

For low Re_b, the Nusselt number Nu (characterising the dimensionless heat flux) behaves as in the standard VC setup[1], whereas at high Re_b, Nu increases with Re_b following the case of passive scalar transport in channel flow[2]. For values of Re_b close to the Reynolds number of the VC flow Re_0, *Nu decreases* relative to the equivalent VC value. As shown in figure 1(c), this drop shows a remarkably consistent behaviour across $10^6 \leq Ra \leq 10^8$ and $1 \leq Pr \leq 10$. This decrease occurs despite an increase in mechanical driving leading to an increased mean wall shear. This finding is reminiscent of sheared Rayleigh-Bénard convection, where a similar drop in heat flux is observed for moderate Re_b[3], although in that case the base (RB) convection flow has zero mean wall shear.

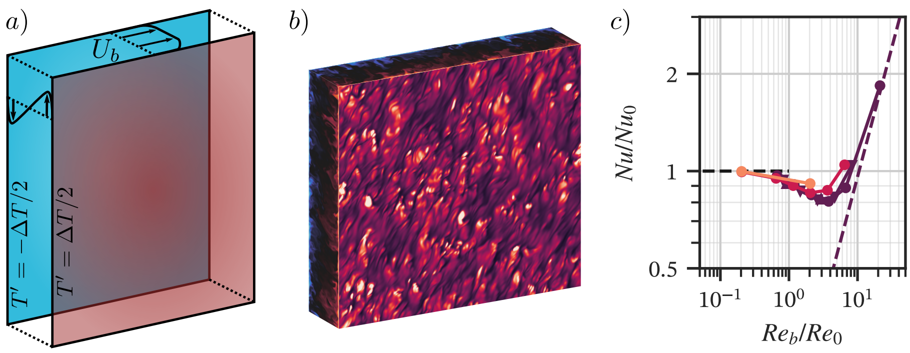

Figure 1: (a) Schematic of the simulation domain and the mean flow components. (b) Snapshot of the wall heat flux and temperature field at $Ra = 10^7$, $Pr = 1$, $Re_b = 10^{3.5}$. At the wall plane, darker colour denotes lower heat flux. (c) Nu against Re_b, normalised by values from the pure VC case for various Ra and Pr.

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