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FURTHER REMARKS ON A MODEL OF TWO-DIMENSIONAL CONVECTION

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IN MY recent article [1] I demonstrated that a certain model of steady two-dimensional convection at high Rayleigh number fails to describe either the motion of a fluid with infinite Prandtl number or the motion of a fluid in a porous medium. G. Roberts of the University of Newcastle-upon-Tyne has pointed out to me that there is an unstated assumption in that model, that the temperature is of unit order-of-magnitude in the vertical boundary layers. If this assumption is replaced by a fifth model balance that $(\vec{u}.\vec{\nabla})\theta \sim \nabla^2\theta$ in that region, allowing $[\theta]$ to be less than unity in order of magnitude, self-consistent models may be constructed.

The balances in the infinite Prandtl number fluid (obtained by G. O. Roberts [27]) are $[u_{int}] = Ra^{3/5}$, $\delta_H = Ra^{-1/5}$, $\delta_v = Ra^{-3/10}$, $[\theta] = Ra^{-1/10}$, $Nu \sim Ra^{1/5}$ (where $[\theta]$ is the order of magnitude of the temperature in the vertical layers), and for motion in a porous medium $[u_{int}] = A^{2/5}$, $\delta_H = A^{1/5}$, $\delta_v = A^{-2/5}$, $[\theta] = A^{-1/5}$, $Nu \sim A^{1/5}$.

The balances for motion of a viscous fluid with large Prandtl number become $[u_{int}] = Ra^{2/3}Pr^{-1/9}$, $\delta_T = Ra^{-1/3}Pr^{2/9}$, $\delta_H = Ra^{-1/3}Pr^{5/9}$, $\delta_v = Ra^{-1/3}Pr^{1/18}$, $[\theta] = Pr^{-1/6}$, $Nu \sim Ra^{1/3}Pr^{-2/9}$ for the Robinson model and $[u_{int}] = Ra^{1/2}Pr^{-1/6}$, $\delta_T = Ra^{-1/4}Pr^{1/12}$, $\delta_H = Ra^{-1/4}Pr^{5/12}$, $\delta_v = Ra^{-1/4}Pr^{-1/12}$, $[\theta] = Pr^{-1/6}$, $Nu \sim Ra^{1/4}Pr^{-1/12}$ for the Pillow model. The conclusion that the viscous boundary layer eventually fills the cell remains valid; it is however now seen that the temperature in the vertical boundary layers decreases in order of magnitude as the Pradntl number increases. The finite Prandtl number model is valid for $Pr \ll Ra^{3/5}$ for both models.

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