

# Entropy Scaling of high-Rayleigh-number convection based on internal convective boundary layer

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**摘要:** We propose a phenomenological model for thermal convection with unity Prandtl number at high Rayleigh numbers. It invokes Kraichnan's (1962) assumption of existence of a high-Reynolds-number internal turbulent boundary layer near each horizontal plate at such Rayleigh numbers. However, we show for the first time that the boundary layer is convective, rather than a shear driven one assumed by Kraichnan. The convective logarithmic friction law of Tong and Ding (2020) is then used to relate the large-scale convection velocity to the induced friction velocity. The predicted scaling relation of the Nusselt ( $Nu$ ) with the Rayleigh number ( $Ra$ ) does not have a power law form. Instead, it is close to  $Ra^{1/3}$  and  $Ra^{4/9}$  respectively for  $Ra \sim 10^{12}$  to  $10^{16}$ , in agreement with experimental results up to  $Ra \sim 10^{15}$ .

The model predicts significant deviations from the apparent  $Ra^{1/3}$  scaling beyond  $Ra \sim 10^{17}$ , slowly approaching the  $Ra^{1/2}$  scaling. In contrast to previous models, the transition from the apparent  $Ra^{1/3}$  scaling to the  $Ra^{1/2}$  scaling occurs within the same regime of convective turbulent boundary layer, with no changes in the leading-order physics. Therefore, our quantitative prediction of the transition range and experimental data within the range can be used to validate the  $Ra^{1/2}$  scaling and the internal boundary layer assumption without a direct observation of the  $Ra^{1/2}$  scaling. The results suggest that data with  $Ra \sim 10^{17}$ - $10^{18}$  are sufficient to definitely validate the scaling. The present work not only reveals the correct boundary layer physics, but also provides a feasible approach to validate the  $Ra^{1/2}$  scaling and an impetus for well-targeted future experiments and simulations at higher  $Ra$ .

**报告人简介:** Dr. Chenning Tong received his BE and ME from BIAA in 1983 and 1986 respectively, and his Ph.D. from Cornell University in 1995. He was a Research Associate at Penn State University from 1995-1999. He then joined Clemson University in 1999 and is a Professor in Mechanical Engineering. His research interests are in the broad areas of turbulence, including turbulent boundary layers, atmospheric turbulence, Rayleigh-Benard convection, turbulent mixing, turbulent combustion, and small-scale turbulence. His current research includes both theoretical and experimental investigations.

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