SCALING OF TEMPERATURE FLUCTUATIONS GENERATED BY FRICTIONAL VISCOUS HEATING

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In practically all flows, viscous friction leads to a loss of kinetic energy, which is converted into heat. The evolution equation for the temperature θ contains therefore always a source term, reflecting the heat generation by viscous energy dissipation ϵ,

$$\partial_t \theta + \boldsymbol{u} \cdot \nabla \theta = \nabla \cdot (D \nabla \theta) + \frac{\epsilon}{c_p} \tag{1}$$

where $\boldsymbol{u}$ is the velocity, D the heat diffusion coefficient and c_p the heat capacity. In a turbulent flow, the question arises how the so-induced temperature fluctuations are distributed over length-scale, since the viscous dissipation is a small scale quantity, but the dissipation-rate fluctuations are correlated at large scales.

Isotropic incompressible turbulence is the simplest framework to help us provide answers to this question. In a recent work [1] the authors have considered this effect of the viscous generation of temperature fluctuations in isotropic turbulent flows using the eddy-damped quasi-normal Markovian (EDQNM) model. Nevertheless, this approach is incapable of predicting the cumulant contributions to the wavenumber spectrum of the dissipation rate fluctuations. Therefore, a numerical study was undertaken, the results of which were published in reference [2]. The direct numerical simulations (DNS) at low Reynolds numbers showed that it is indeed the large-scale correlation of the dissipation-rate fluctuations which determines the morphology of the heat-generation. Clear scaling ranges were however not obtained.

In the present work, we will check the different assumption for the scaling laws in a wide range of the Reynolds (Re) and Prandtl (Pr) numbers using high resolution direct numerical simulations using an original approach to compute the heat fluctuations, allowing to consider large values of the Prandtl number at a reasonable numerical cost [3]. It is shown that at high Reynolds numbers the temperature variance and temperature dissipation become independent of the viscosity. Scaling relations are derived and verified. Figure 1 illustrates the Péclet number ($Pe = Re\ Pr$) dependence of the variance of heat fluctuations θ^2 and its dissipation ϵ_θ.

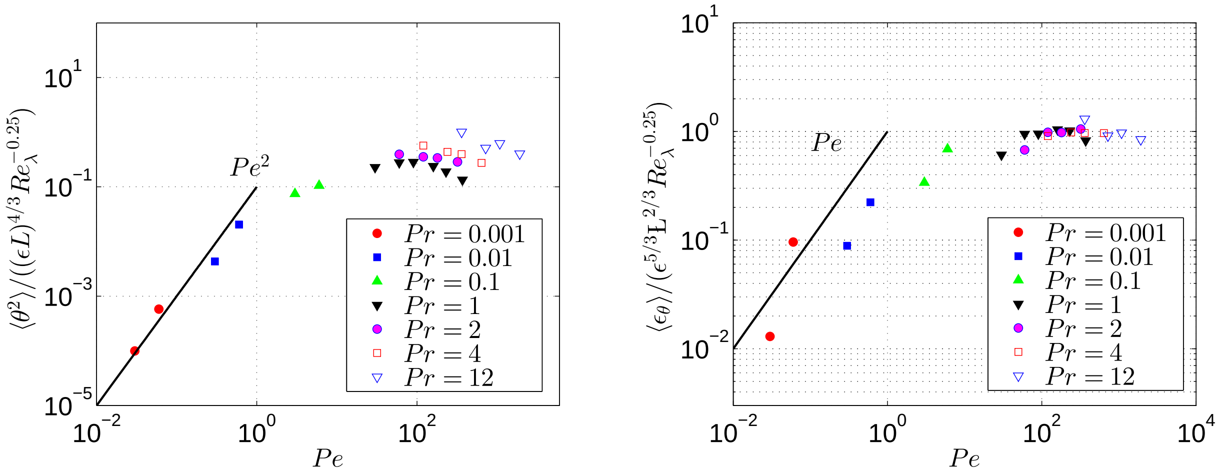

Figure 1. Péclet number dependence of the normalized temperature variance and the normalized dissipation of temperature fluctuations. The integral scale of the flow is denoted L and the Taylor-scale Reynolds number R_λ.

References

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