Mixing in turbulent flows: Finite Reynolds number effects

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Solving the 'theory of turbulence' supposes the ability to predict the statistical behavior of any turbulent field. The ideal solution would be a tractable quantitative theory, based soundly on the underlying physics, as described by the Navier-Stokes equations. The theory proposed by Kolmogorov in 1941 postulated that for sufficiently large Reynolds numbers, the small scale motion (SSM) is statistically independent of the large scales. It follows that the SSM should be statistically universal and locally isotropic, and described via simple parameters such as the kinematic viscosity of the fluid and the mean dissipation rate. Passive scalars (temperature, humidity, dye) should obey the same postulates.

However, numerous experimental and numerical studies have indicated that the small scales of both velocity and scalar fields are significantly affected by the flow-dependent large scales, either because of the large scale anisotropy which propagates down to the smallest scales, or, simply because the Reynolds number is finite (this is usually referred to as the FRN effect). Realistically, in order to predict turbulent mixing we need to improve our understanding of the physics underlying this phenomenon and to formally account for the effect the large-scales (often anisotropic) have on the SSM, without ignoring FRN effects. The focus is on two-point statistics, where the two space points $\mathbf{x}$ and $\mathbf{x}^+$ are separated by the increment vector r.

In this seminar, scale-by-scale energy budget equations for high-order moments of the scalar increment are:

-formulated with an explicit account of the finite Reynolds number effect, and
-assessed using direct numerical simulations of several flows at different Reynolds numbers. Special emphasis is laid on the scaling of the ‘source’ term that directly connects the instantaneous dissipation rate to the local variance of the scalar. Thus, the effect of internal intermittency is entangled by a complex mechanism involving both small and large scales.
The equations are further analyzed to show that the similarity scales (i.e. variables which allow for perfect collapse of the normalized terms in the equations, or an affine transformation of these terms) are, for the second-order moments, fully consistent with Kolmogorov-Obukhov-Corrsin theory. However, for high-order moments adequate similarity scales are built from high-order moments of the dissipation rate of the scalar variance.

We finally emphasize that any phenomenological theory of small scale turbulence must meet the constraints imposed by the transport equations of high-order moments that are derived from the first principles.

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