Johns Hopkins University

Center for Environmental & Applied Fluid Mechanics

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Link for Spring 2026 recordings

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"Entropy and Fluctuation Relation in Isotropic Turbulence"

Abstract: Turbulence is inherently a multi-scale phenomenon in which nonlinear cascades mediate the redistribution of energy across scales and govern key flow characteristics, including dissipation, scalar mixing, and dispersion dynamics. Turbulent cascades have been rigorously analyzed within the framework of fundamental fluid mechanics, yet their underlying mechanisms and causal origin are not yet fully understood. There has been growing interest in applying concepts from nonequilibrium thermodynamics to classical turbulence. A central motivation is to investigate whether the attractor of turbulent flows can be characterized by a variational or maximal principle analogous to the second law in equilibrium thermodynamics, and whether the cascade operates to maximize or minimize the entropy-production rate.

In our work, the entropy generation rate in 3D homogenous isotropic turbulence can be defined using local properties from the Kolmogorov-Hill equation, featuring the energy cascade rate as well as the `temperature of turbulence' at a prescribed inertial-range length-

scale. The fluctuation relation (FR) from non-equilibrium thermodynamics that predicts exponential behavior of positive to negative entropy production rate PDFs has been tested using instantaneous flow fields from isotropic turbulence data at Reynolds numbers $Re_\lambda = 1250$ and $Re_\lambda = 433$. We also test the single-time FR in relation to the Kolmogorov refined similarity hypothesis, confirming that FR holds even when conditioning on different values of locally averaged molecular dissipation rates. We further examine the finite-time averaged FR over intervals extending from one to several eddy turnover times, finding that the FR remains valid, although the PDFs of the entropy generation rate deviate from a purely exponential form. A key result is that finite-time averaging must be performed within the Lagrangian framework, i.e. integrating along fluid trajectories using the filtered convective fluid velocity. In contrast, the FR fails when using the Eulerian framework, i.e. time-averaging at fixed positions. Finally, we attempted to extend the framework and define entropy generation rate in 2D turbulence, which is fundamentally different from 3D turbulence because the inverse cascade is dominant. Some preliminary results and conclusions are also discussed.

For more details, visit: https://fusep.ustc.edu.cn/2026/01/21/hanxun-yao/

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