PRECURSORS OF WALL TURBULENCE

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The manner in which infinitesimal disturbances can cause organized fluid motion to become chaotic is an intriguing phenomenon. In addition to being of great theoretical interest, laminar-to-turbulence transition is of significant engineering importance due to its role in heat transfer, its influence on momentum mixing, and its effect on drag. In this work, we present complementary theoretical analyses, high-fidelity direct numerical simulations and data-enabled predictions of transition to turbulence in boundary layers.

The proceedings of transition are not unique, and various pathways can ultimately lead to boundary-layer turbulence. In engineering applications, the presence of free-stream disturbances promotes early breakdown to turbulence, and transition is said to "bypass" other routes that have been traditionally examined using stability theory. Numerical simulations of this bypass transition process reveal that high-frequency disturbances from the free stream are expelled by the boundary-layer shear – a phenomenon known as shear sheltering. Using asymptotic analysis, we develop a physical understanding of the mechanics of shear sheltering, and explain how low-frequency free-stream perturbations can permeate the mean shear. These elongated disturbances force the boundary layer resonantly and lead to the amplification of streaks. While the majority of the laminar streaks are innocuous, a small proportion undergoes a localized instability and breaks down to turbulence. Reports in the literature present conflicting views on the origin of streak breakdown – a matter that we address by performing secondary instability analyses of realistic streaks as well as using artificial neural networks. The predicted streak instabilities are shown to cause breakdown to turbulence in complementary direct numerical simulations.

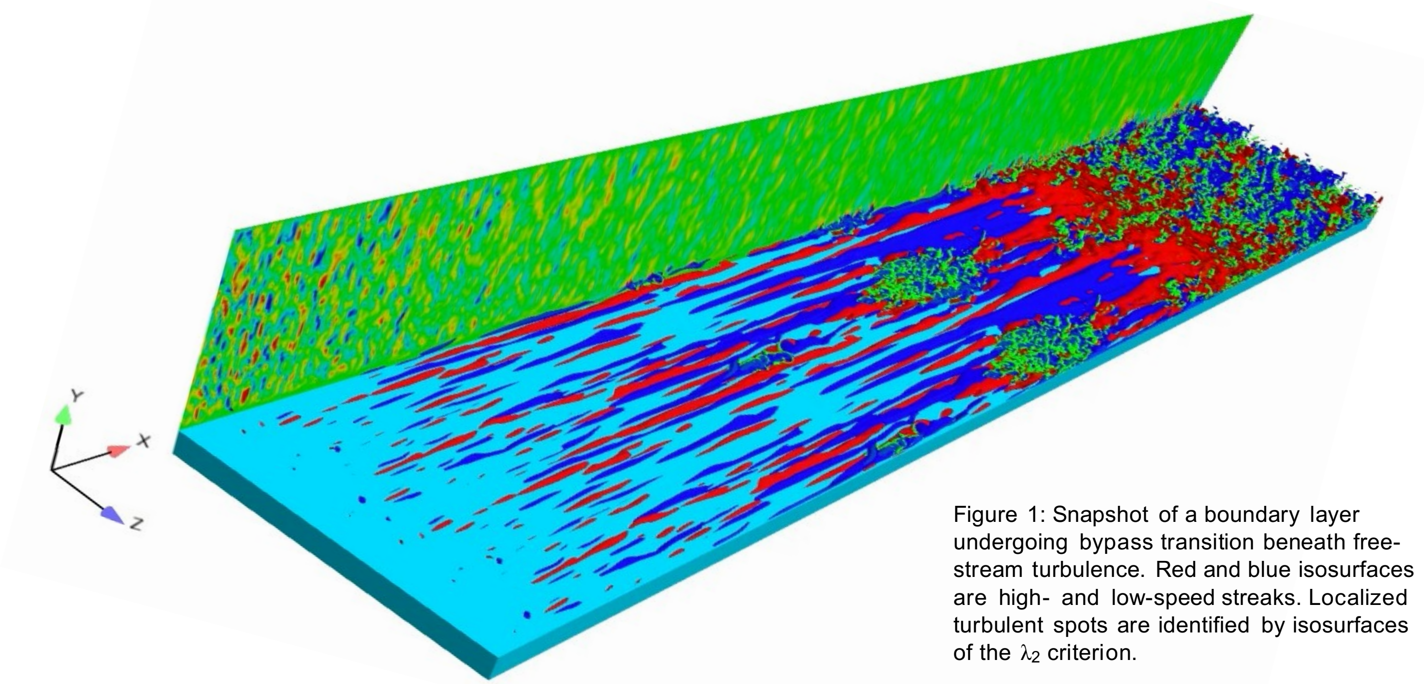

Figure 1: Snapshot of a boundary layer undergoing bypass transition beneath free-stream turbulence. Red and blue isosurfaces are high- and low-speed streaks. Localized turbulent spots are identified by isosurfaces of the λ_2 criterion.

Tamer Zaki is an associate professor in the Department of Mechanical Engineering at Johns Hopkins University. His current research activity spans transitional and turbulent shear flows, interfacial flows and complex fluids. Dr. Zaki received his PhD in 2005 from Stanford University where he was a member of the *Flow Physics and Computational Engineering* group. He participated in the Department of Energy Advanced Simulation and Computing (DoE-ASC) program both at Stanford and at Los Alamos National Lab where he was awarded the *"Directors Fellowship"*. He joined the faculty in the Department of Mechanical Engineering at Imperial College London (2006–2012) where he established the *Flow Science and Engineering* group, followed by his current appointment at Johns Hopkins. He is a member of the Johns Hopkins Institute of Data Intensive Engineering and Science (IDIES), the Center for Applied and Environmental Fluid Mechanics (CEAFM), the *American Physical Society* and the Editorial Advisory Board of *Flow, Turbulence and Combustion*.