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Turulent-Laminar Patterns in Pipes and Channels[1]

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When fluid flows through a channel, pipe, or duct, there are two basic forms of motion: smooth laminar motion and complex turbulent motion. The discontinuous transition between these states is a fundamental problem that has been studied for more than 100 years. What has received far less attention is the large-scale nature of the turbulent flows near transition once they are established. We have carried out extensive numerical computations in pipes and channels to investigate the nature of transitional turbulence in these flow. We show the existence of three fundamentally different turbulent states separated by two distinct Reynolds numbers. In the case of pipe flow for example, below Re approximately 2200, turbulence takes the form of familiar equilibrium (or long-time transient) puffs. The turbulence is intensive – puffs are localized and the ratio of turbulent to laminar flow is not dictated by system size but by factors such as initial conditions. At $Re = 2200$ the flow makes a striking transition to extensive turbulence where the amount of turbulent flow scales with pipe length. The asymptotic state is an irregular (intermittent) alternation of turbulent and laminar flow whose complexity is inherent and does not result from random initial disturbances. Intermittency continues until $Re = 2500$ where the intermittency factor, and other measures, reveal a continuous transition to a state of uniform turbulence along the pipe. We argue that these states are a manifestation of universal large-scale structures in transitional shear flows.

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