Structure and mechanism of turbulence under dynamical restriction in plane Poiseuille flow

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The perspective of statistical state dynamics (SSD) has recently proven useful in studying the mechanisms underlying turbulence in a variety of physical systems. In the case of wall-turbulence a second order closure, referred to as stochastic structural stability theory (S3T), has provided insight into the dynamics turbulence in Couette flow and specifically the emergence and maintenance of the roll/streak structure. When implemented as a coupled set of equations for the streamwise mean and perturbations, this closure eliminates nonlinear interactions among the perturbations restricting nonlinearity in the dynamics to that of the mean equation and interaction between the mean and perturbations. Simulations at modest Reynolds numbers reveal that the essential dynamics of Couette turbulence are retained when the dynamics are restricted in this manner. In this paper this restriction of the dynamics is used to obtain a dynamical system, referred to as the restricted non-linear (RNL) system, which is applied to study the structure and dynamics of turbulence in plane Poiseuille flow at moderately high Reynolds numbers. Remarkably, the RNL system spontaneously limits the support of its turbulence to a small set of streamwise Fourier components giving rise to a natural minimal representation of its turbulence dynamics. Although greatly simplified, this RNL turbulence exhibits realistic structures and statistics. Surprisingly, even when a further truncation of the perturbation support to a single streamwise component is imposed the RNL system continues to produce realistic turbulent structure and dynamics. The turbulent flow in RNL simulations at the Reynolds numbers studied is dominated by the roll/streak structure in the buffer layer and very-large-scale structure (VLSM) in the outer layer. In this work diagnostics of the structure, spectrum and energetics of RNL and DNS turbulence are used to demonstrate that the roll/streak dynamics supporting the turbulence in the buffer and log-layer is essentially similar in RNL and DNS.