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Self-Sustaining Process and Exact Coherent Structures in Shear Flows

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The Self-Sustaining Process (SSP) is a weakly nonlinear theory of a fundamental three-dimensional nonlinear process in shear flows. It is the basic mechanism that enables enhanced momentum transport and the redistribution of the mean shear energy into smaller scales and, ultimately, turbulent motions. I will briefly review the 40 years of observations of streaks and coherent structures in the near wall region of turbulent shear flows that led to the formulation of the SSP theory. A primary impact of the SSP, besides providing some level of mechanistic understanding, has been to provide a method to calculate unstable traveling wave solutions of the Navier-Stokes equations. This approach has now been successfully carried out in all canonical wall-bounded shear flows with stress as well as velocity boundary conditions. The traveling waves thus obtained show striking similarity with the observed near-wall coherent structures, earning them the name of 'exact coherent structures'. Furthermore, those unstable waves have been shown to capture basic statistics of turbulent flows remarkably well, thereby providing hope for a quantitative theory of turbulence over smooth walls. The traveling waves come in many kinds: small scales, large scales and multi-scales. The asymptotics of the large scale traveling waves as the Reynolds number goes to infinity is remarkably simple and confirms the asymptotic validity of the SSP. These large scale coherent states may yield a new promising target for the control of turbulence in shear flows.