Coherent dynamics in near-wall turbulence

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Although much attention has been granted in recent years to the compact coherent structures of homogeneous turbulence, the role of similar structures in the near-wall region of wall-bounded flows is arguably even more important. Thus, while in homogeneous turbulence the vortices lie at the end of the Kolmogorov energy cascade, and are presumably part of a relatively passive dissipation machinery, those of the near-wall region, even if also scaling in Kolmogorov (wall) units, are net generators of turbulent energy, part of which is exported to the rest of the flow and contributes to maintain it. In this presentation I will attempt to summarize what has been learned in the past decade about the properties and significance of these near-wall structures.

Most of the perturbation vorticity in the wall region below $y^+ \approx 50$ can be described in terms of velocity streaks, which are forward- or backwards-flowing jets superimposed on the mean shear, and quasi-streamwise vortices. The active elements seem to be the backwards-flowing low-velocity streaks, which are very elongated, with lengths of the order several thousand wall units, and a spanwise pitch $\Delta z^+ \approx 100^+$. The high-velocity components of the streak array are shorter $\Delta x^+ \approx 300$. That is also the length of the streamwise vortices, or at least of how long they remain in the near-wall region. Several vortices are associated with each low-velocity streak, arranged in staggered counter-rotating pairs, and maintain it by pumping low-velocity fluid away from the wall. It is believed that the breakdown of the streak generates the vortices, and that the catenation of both processes forms a self-sustaining regeneration cycle. Candidate instabilities have been identified numerically and analytically, with eigenfunctions which can be interpreted as deriving from oblique waves in either corrugated vortex sheets or in elliptical jets, and which strongly resemble the arrangements educed from real turbulent flows.

A slightly different interpretation is that the cycle is organized around a nonlinear travelling wave, a fixed point in phase space which represents a non-uniform streak accompanied by a vortex pair. This is not too different from the previous model, which essentially assumes that the undisturbed streak is a fixed point in phase space, and that the cycle is an approximation to a homoclinic orbit running through it. Candidate nonlinear waves have been computed by several groups, and reduced dynamical models based on this approach have been formulated. An example is given in figure 1(a).

It can be shown, by means of numerical experiments which mask the influence of the outer flow, that this generation cycle is autonomous, in the sense that it can run by itself without any input from the exterior [1]. In can also be shown that the cycle is able to run on a single copy of the fundamental nonlinear solution which, depending on the parameters of the numerical masking procedure, is either a permanent wave, oscillates, bifurcates to chaos, or bursts intermittently [2]. Moreover, when the autonomous numerical box is made wide and long enough to contain many independent structures, it organizes itself into spatio-temporal patterns whose spectra are essentially indistinguishable from those of the near-wall region of full flows (figure 1b). There is however evidence of some modulation of the near-wall structures by the outer region in real flows, which results in a broadening of the spectra with increasing Reynolds numbers.

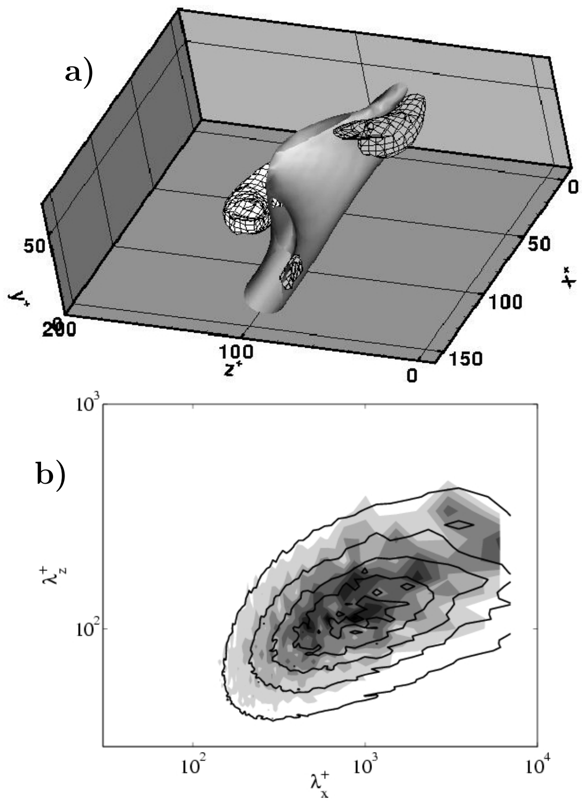

Figure 1: (a) The smoothly shaded object is an isosurface of negative perturbation velocity in a numerically modified near-wall region, and marks the location of a streak. The meshed objects are the counter-rotating streamwise vortices that 'shepherd' it [2]. The whole arrangement is a permanent wave that advects with a velocity $U_c \approx 14^+$. (b) Two-dimensional premultiplied spectrum, $k_x k_z E_{uu}$, plotted as a function of the two wavelengths $\lambda = 2\pi/k$. The lines are for a full channel at $Re_\tau = 190$, while the shaded contours are for an autonomous wall region. In both cases $y^+ = 16$.

References

[1] Jiménez, J. & Pinelli, A. (1999) The autonomous cycle of near wall turbulence, *J. Fluid Mech.* **389**, 335–359.

[2] Jiménez, J. & Simens, M. P. (2001) Low-dimensional dynamics in a turbulent wall, *J. Fluid Mech.* **435**, 81–91.