Non-linear optimal perturbations in a boundary-layer flow

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ABSTRACT

Recent studies suggest that non-linearity rather than non-normality is the primary cause of laminar-turbulent transition in shear flows (see, e.g., Waleffe, 1997). Thus, in this work we look for a localized perturbation able to lead optimally a boundary-layer flow to a chaotic state, following a purely non-linear route. Localized perturbations have been computed by means of an energy optimization which includes the non-linear terms of the Navier-Stokes equations. Optimizations have been performed out for several Reynolds numbers, target times T, domain lengths, and initial energies E_0. Non-linear optimal perturbations are found to induce an energy amplification much larger than the linear ones. They are localized in the streamwise and spanwise directions, and characterized at $t = 0$ by a series of streamwise alternated vortices, with a finite inclination with respect to the streamwise direction (see Fig. 1); they strongly differ from the linear ones which are more extended in space and composed by streamwise vortices and streaks (see Cherubini et al., 2010). Non-linear optimals are found to induce transition for lower levels of the initial energy than their linear optimal counterparts. Transition is induced following a route which does not rely on the presence of streamwise-invariant streaks nor vortices. Instead, Λ vortices are observed, which are then connected by a spanwise vortex filament, originating hairpin vortices with low-speed streaks between their legs. Such coherent structures are maintained for some time, until a fully turbulent state ensues. Similar structures have been observed in the DNS by Wu & Moin (2010), showing that, even when it is not initialized by the optimal perturbation, the flow reaches transition following a route which approximates the optimal one. This suggests that a purely non-linear preferential route exists connecting the laminar to the turbulent state.

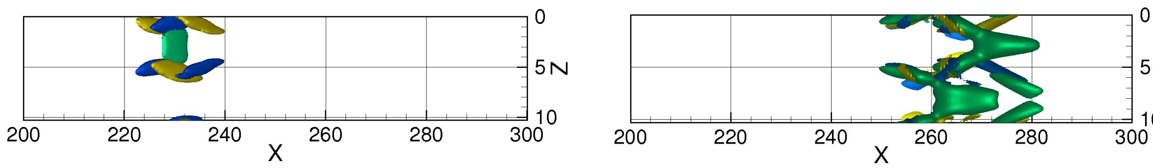

Figure 1: Initial and final non-linear optimal perturbations for $T = 75$, $E_0 = 0.01$: iso-surfaces of the streamwise velocity (green) and vorticity (blue for negative and yellow for positive values).

REFERENCES

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