Transition to turbulence in the bottom boundary layer under a solitary wave.

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In this study we explore the transition to turbulence in the unsteady bottom boundary layer (BBL) driven by a surface solitary wave. Based on the experimental observation reported by Sumer *et al* [1] for such a base flow, two potential transition scenarios exist. The primary scenario is associated with the classical transition resulting from the breakdown of the exponentially growing 2D Tollmien-Schlichting waves. We show that this time varying flow can be characterized as stable, conditionally unstable and unconditionally unstable. The alternative scenario consists of a characteristically different path to transition, resulting from the formation of localized turbulent spots. The formation of these turbulent spots leads to a bypass transition to turbulence. We show that this flow is able to produce high gains of energy for 3D structures resembling elongated streaks by means of non-modal stability analysis. Furthermore, the evolution of the streaks into the turbulent spots is captured using a fully non-linear three dimensional direct numerical simulation with a spectral multidomain penalty method model.

The unsteady bottom boundary layer flow is generated by the interaction of a passing solitary wave with the bottom surface of the ocean. The main interest of this study is to predict the sediment transport produced by tsunamis or waves with high temporal separation between them. This free surface flow presents an analytic solution, neglecting viscosity and space variation with the streamwise direction, which is

$$U(t) = U_{0,m}\mathrm{sech}(\omega t)^2, \qquad (1)$$

where $U_{0,m}$ is the maximum velocity, that appears when the peak of the wave is passing over a given point, and ω is the frequency of the wave. If the viscosity is taken into account [2], the flow that is created is an unsteady boundary layer with an acceleration phase followed by a deceleration phase, in which there is a region of flow reversal.

Recently, Sumer et al. [1] performed experiments in a long water tunnel in which the flow was driven by a piston, and they were able to reproduce the external velocity field defined by Eq. (1). The main result of this research was that for low Reynolds numbers, the flow was stable. At a given Reynolds number, the flow was unstable to bidimensional instabilities (rolls), that were closely related to Tollmien-Schlicting waves in boundary layer stability theory. In these range of Reynolds numbers, the flow could present also a transition to turbulence through turbulent spots, before the appearance of the 2D rolls.

The 2D stability analysis was studied in [3] in which, a very similar transition scenario to the experiments was predicted. There was a Reynolds number below which no instabilities appear, and a region of Reynolds numbers in which the flow became unstable depending on the initial condition (conditionally unstable). For Reynolds numbers greater than a given one, the flow was always unstable.

In the case of the transition to turbulence through turbulent spots, we show that this unsteady boundary layer is able to produce high gains of energy in short times due to non-normal growth. The process can be seen as a bypass transition, as in the case of a steady boundary layer. Thus, the theory of the optimal growth for unsteady non-periodic flows is applied to this problem to show that there is the possibility of 3D growth before the flow becomes unstable with respect to 2D instabilities (see FIG. 1). We explore the results for different wave numbers an compare with DNS simulations of the same problem, providing very accurate results.

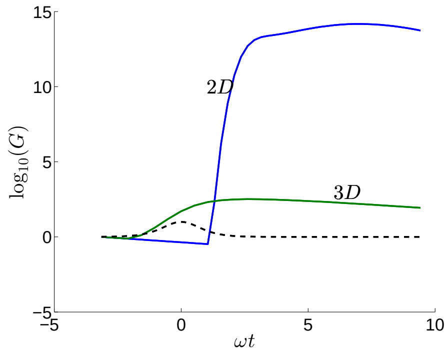

FIG. 1. Gain of 2D and 3D optimal disturbances in blue and green respectively. In dashed line is plotted the total energy of the system.

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