An experimental investigation of the laminar horseshoe vortex around an emerging obstacle.

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An emerging long obstacle placed in a boundary layer developing under a free-surface generates a complex horseshoe vortex (HSV) system, which is composed of a set of vortices exhibiting a rich variety of dynamics. The present experimental study examines such flow structure and characterizes precisely, using PIV measurements, the evolution of the HSV geometrical and dynamical properties over a wide range of dimensionless parameters (Reynolds number $Re_h \in [750, 8300]$, boundary layer development ratio $h/\delta \in [1.25, 4.25]$ and obstacle aspect ratio $W/h \in [0.67, 2.33]$).

The dynamical study of the HSV is based on the categorization of the HSV vortices motion into an enhanced specific bi-dimensional typology, separating a coherent (due to vortex-vortex interactions) and an irregular evolution (due to appearance of small-scale instabilities), as shown in figure 1. This precise categorization is made possible thanks to the use of vortex tracking methods applied on PIV measurements, A semi-empirical model for the HSV vortices motion is then proposed to highlight some important mechanisms of the HSV dynamics, as (i) the influence of the surrounding vortices on a vortex motion and (ii) the presence of a phase shift between the motion of all vortices. The study of the HSV geometrical properties (vortex position and characteristic lengths and frequencies) evolution with the flow parameters shows that strong dependencies exist between the streamwise extension of the HSV and the obstacle width, and between the HSV vortex number and its elongation. Comparison of these data with prior studies for immersed obstacles reveals that emerging obstacles lead to greater adverse pressure gradients and down-flows in front of the obstacle.

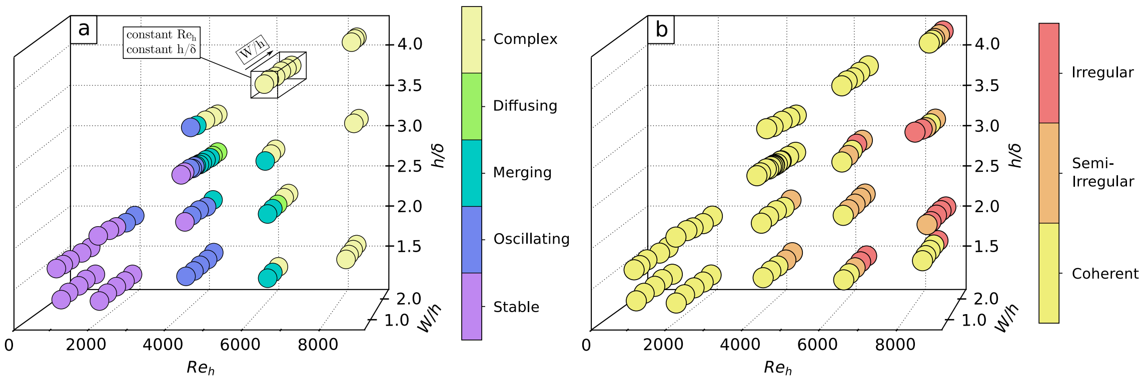

Figure 1: (a) Coherent regimes evolution as a function of the three dimensionless parameters of the study. Each circle, representing a measured flow, is coloured according to the observed HSV regime. (b) Irregular regimes evolution. These evolutions establish well the dependence of the HSV coherent regimes to the three dimensionless parameters, and the main dependence of the irregular regimes to the Reynolds number.