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INSTABILITY OF STATIONARY STREAMWISE VORTICES EMBEDDED IN A SWEPT-WING BOUNDARY LAYER

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1 Motivation

Research results on transition to turbulence in boundary layers testify to a pronounced contribution of stream-wise vortices and streaky structures to the laminar flow breakdown. Modulating the base flow, they generate local velocity gradients with high-frequency instabilities starting to grow. The same applies to a swept-wing flow which is unstable to stationary crossflow vortices, the latter being subject to amplifying secondary oscillations. A number of experimental, theoretical and numerical studies has been performed on this topic indicating that the instability phenomenon under the consideration is of much importance during the boundary-layer transition, e.g., [1, 2, 3, 4, 5]; for an overview of the problem see [6].

In the present work we deal with the secondary disturbances of a swept-wing flow perturbed by the stationary vortices at their different transverse spacing. Most of all we are interested in the effect of the spatial arrangement of the vortices on the high-frequency boundary-layer oscillations. To make it clear, wind-tunnel experiments were performed focusing on the laminar flow disturbances excited in a controlled manner.

2 Experimental set-up

The experimental runs were carried out at the Department of Thermo and Fluid Dynamics, Chalmers University of Technology. A wing model with a C-16 profile was tested at a 45 degree sweep angle. The stationary vortices were generated in the laminar boundary layer by an elongated and a circular roughness elements placed one by one on the wing surface. The first of them produced at its tips a pair of isolated vortices of opposite rotation while the second element generated the vortices interacting with each other as is sketched in figure 1. The high-frequency harmonic perturbations evolving along the vortices were excited through a tiny hole on the wing surface behind the roughness elements. In each case, the secondary oscillations were excited underneath the primary vortices.

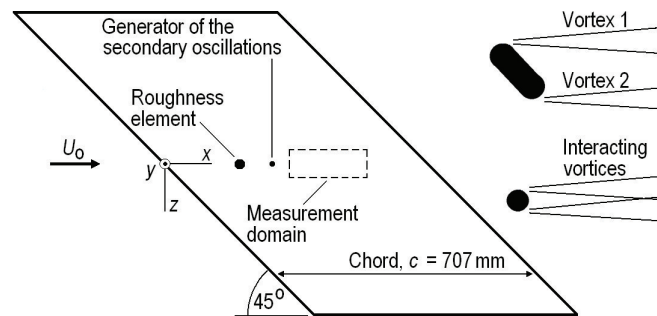


Figure 1: Experimental model and roughness elements generating the stationary vortices.

The flow pattern was examined through hot-wire measurements with single and V-wire probes which were positioned by a computer controlled traversing mechanism. To observe the secondary perturbations, velocity measurements at each point in the spatial domain were phase-locked with the disturbances generator so that volumetric flow patterns were created. Some of the obtained results are illustrated here as iso-surface plots of the nonstationary velocity component taken at a fixed time moment.

3 Wind-tunnel data

In the flow disturbed by the elongated roughness element two vortices (Vortex 1 and Vortex 2) are generated originating at the left-hand and the right-hand sides of the element, respectively. Spaced in the transverse direction, they seem to develop without significant interaction with each other. When changing the elongated



roughness element to the circular one, the counter-rotating vortices interfere at diminution of their spacing, thus, it is expected that mean-velocity gradients generated by the vortices become smaller and the boundary layer is stabilized to the high-frequency disturbances.

Indeed, such an effect was observed comparing the secondary oscillations evolving along the isolated and interacting vortices, an example is given in figure 2. In both cases, the disturbances were excited at low levels of the periodic forcing so that linear oscillations were induced at the position of their generator. As is seen, they appear as oblique waves which are transported in narrow regions of the basic-flow stationary modulation. Riding on the isolated vortex the perturbations are well periodic in the major part of the measurement domain, while propagating away from the generator they amplify and finally result in chaotic motion. One observe that the periodicity of the oscillations is contaminated by small-scale irregularities in the aft part of the box shown at the left of figure 2 testifying to a broad spectrum of velocity fluctuations. Otherwise, at the vortex interaction, the high-frequency disturbances do not evolve into 3D irregular structures so that their coherence is found in the entire measurement domain.

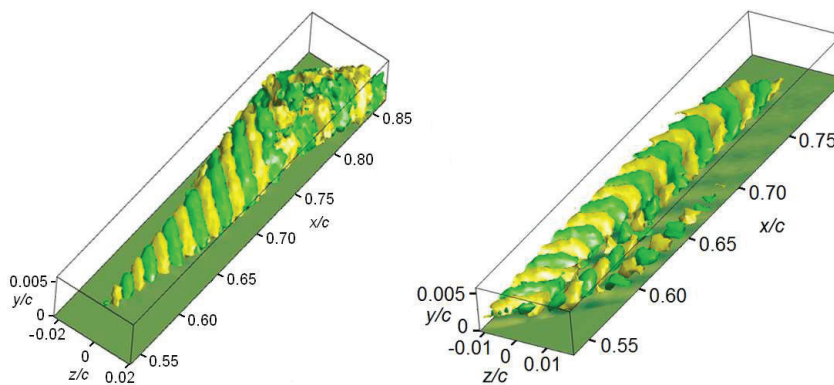


Figure 2: Controlled perturbations of Vortex 1 (*left*) and of the interacting vortices (*right*). Chord Reynolds number is 390,000, excitation frequency is 210 Hz, amplitude levels shown in *yellow* and *green* are $\pm 0.5\%$ of U_0 (*left*) and $\pm 0.1\%$ of U_0 (*right*).

Our conclusion is that the behavior of secondary perturbations involved in the swept-wing transition is quite different depending on the transverse spacing of the primary basic-flow disturbances. That is, amplification of the secondary oscillations is obviously reduced when the isolated counter-rotating vortices start to interact, approaching each other. In this way, the transitional flow can be controlled by roughness elements of a proper configuration, modulating the primary boundary layer perturbations and their secondary instabilities.

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