Control of Nonlinear Traveling Crossflow Disturbances Using Plasma Actuators

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In the leading-edge region on swept airplane wings and wind-turbine rotor blades, the crossflow (CF) instability mechanism dominates the laminar-turbulent transition in the 3-d boundary layer with favorable pressure gradient. In the recent years an increasing number of investigations have demonstrated the applicability of plasma actuators to control the CF-dominated transition using different approaches, such as (i) the upstream-flow-deformation (UFD) / distributed-roughness-elements (DRE) strategy, see e.g. [1, 2], (ii) the base-flow manipulation, see e.g. [3], or (iii) the direct attenuation of steady nonlinear crossflow vortices (CFVs), see e.g. [4]. In the present work, we focus on the most unstable traveling/unsteady CFV mode, which prevails in case of high free-stream turbulence. Following the work by Dörr and Kloker [4], actuator rows with one actuator per fundamental wavelength are used to directly tackle the nonlinear disturbance state. The actuators are operated in unsteady fashion to attenuate the primary CFVs moving over them. The effects of the orientation and the length of the actuators, and the phase and the waveform of the time signal are investigated.

It is demonstrated that unsteady actuators aligned with the oncoming CFVs, operated with a suitable phase, can efficiently attenuate them. However, steady modes are also excited due to the

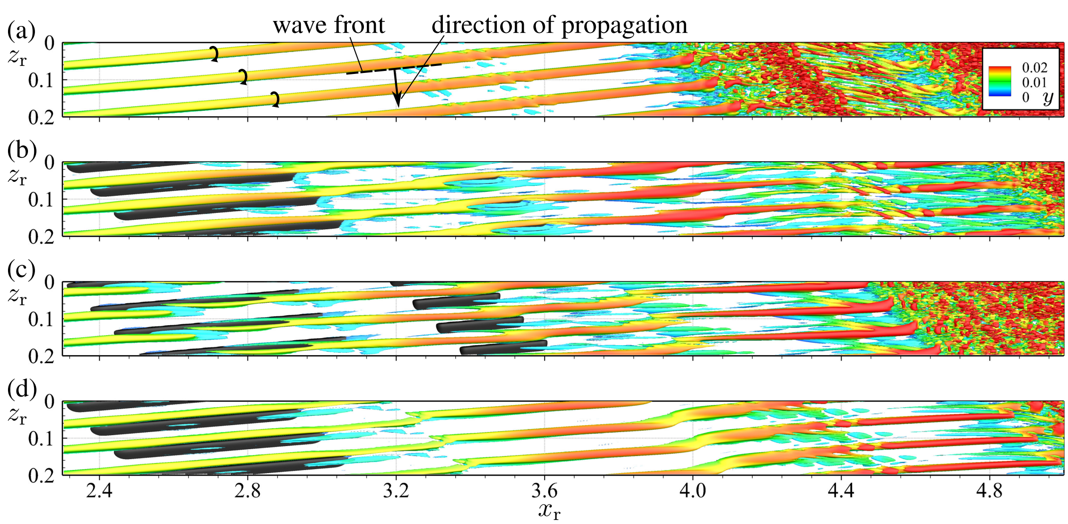

Figure 1: Vortex visualization (snapshots, $\lambda_2 = -2.5$, color indicates y) and the body-force set-up ($f_{10\%}$-isosurface, black) for (a) the reference case at $t/T_0 = 11.25$, (b) and (c) the case with two actuator rows at $t/T_0 = 11.25$ and 11.57, respectively, and (d) the case with pure sinusoidal time signal at $t/T_0 = 11.25$.

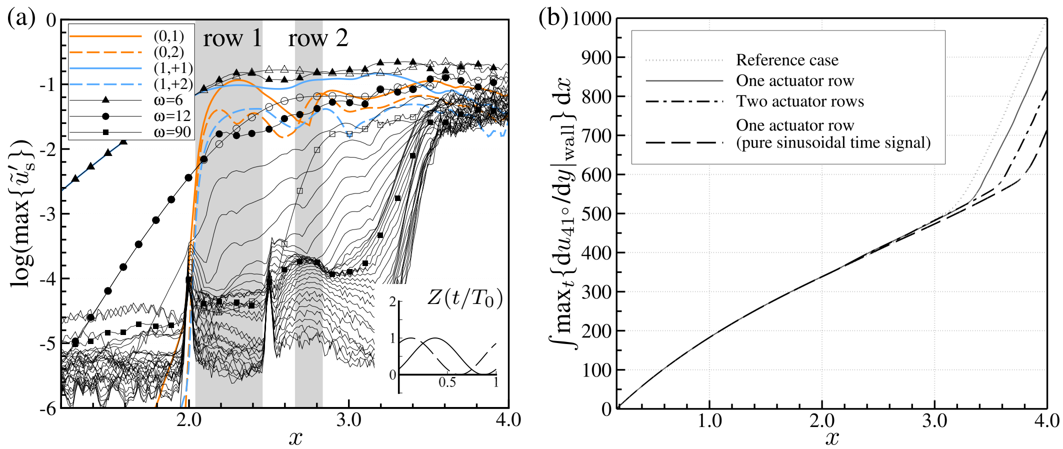

Figure 2: (a) Downstream development of modal $\tilde{u}'_{s,(h,k)}$- and $\tilde{u}'_{s,(h)}$-amplitudes from Fourier analysis (maximum over y or y and z, $0 \leq \omega \leq 180$, $\Delta\omega = 6$) for the case with two actuator rows. Open symbols denote the reference case. The unsteady actuation signal $Z(t/T_0)$ of the first (solid line) and second (dashed line) actuator row over a fundamental period T_0 is added. (b) Downstream development of the in chordwise direction integrated wall-normal gradient of the spanwise mean velocity component in the direction of the oncoming flow at the wall for different cases.

non-zero steady mean of the body force. The primary vortical structures are modulated by superposition of the steady modes, leading to the emergence of isolated structures associated with strong local vorticity concentrations, rendering some parts of the main CFVs more unstable. However it is shown that extending the actuator's length can decrease the receptivity of the misaligned steady modes and increase the efficiency of the transition delay. Furthermore, adding a second actuator row downstream can destroy the isolated structures with strong vorticity concentrations and suppress the growth of the secondary disturbances for a longer distance, see Fig. 1(b) and 1(c) for vortical structures arising from the actuation, and Fig. 2(a) and 2(b) for the modal amplitude and the skin-friction developments, respectively. In an additional case, actuation using a pure sinusoidal time signal with alternating force direction and without steady part is examined. Due to the minimized steady modes, the transition can be distinctly delayed even by employing only one actuator row, see Fig. 1(d) and 2(b).

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