Numerical Investigations on TS-Wave Attenuation Using Plasma Actuator Vortex Generators

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Delaying the laminar-to-turbulent transition on aerodynamic surfaces is of great importance for the development of future aircraft because the skin-friction drag is significantly lower for the laminar boundary-layer state. In recent years, plasma actuators were shown to be applicable as transition-control devices, and transition has been successfully controlled in both 2-d [1, 2] and 3-d [3, 4] (crossflow dominated) base flows. Following the approach investigated in detail by Fransson and co-workers [5], Barckmann et al. [6] employed plasma actuators to excite counter-rotating longitudinal vortices in a Blasius flow. The vortices generate high- and low-streamwise-velocity streaks, stabilizing the flow with respect to the amplification of TS waves by both a mean-flow distortion and imposing three-dimensionality. In the current work two fundamentally different actuator configurations are considered: a symmetrical one, exciting counter-rotating vortices, and a non-symmetrical one, exciting co-rotating vortices. We discuss the differences between these configurations and scrutinize the respective stabilization of the flow, employing direct numerical simulations (DNS).

The actuator set-ups and the resulting vortical structures are visualized in Fig. 1. For case Sym counter-rotating vortices arise, for case NonSym co-rotating ones, their vortical motions possibly hindering each other. Note that for case NonSym the vortices are deflected in positive z-direction due to the resulting spanwise-mean velocity in spanwise direction w_{zm} caused by the forcing.

The effect of the plasma actuation on the development of 2-d TS test modes excited upstream

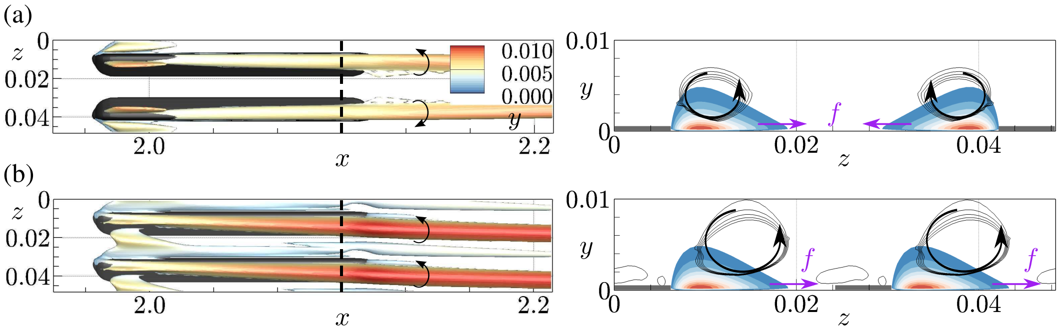

Figure 1: Left: vortex visualization ($\lambda_2 = -2$, color indicates y) and body-force distributions ($f_{10\%}$-isosurfaces, $f_{10\%} = \max\{|f_z|\}/10$, dark). Right: crosscut along the dashed lines at $x = 2.1$ ($\delta_{99,\mathrm{BF}}(x = 2.1) \approx 0.023$). Color indicates $|f_z|$, the lines show λ_2-isocontours (levels -10 to -2, $\Delta = 2$). The gray surfaces indicate the exposed electrodes. (a) Case Sym, $f_{10\%} = 0.055$, force levels in crosscut: 0.05 to 0.55, $\Delta = 0.056$. (b) Case NonSym, $f_{10\%} = 0.109$, force levels in crosscut: 0.10 to 1.09, $\Delta = 0.099$.

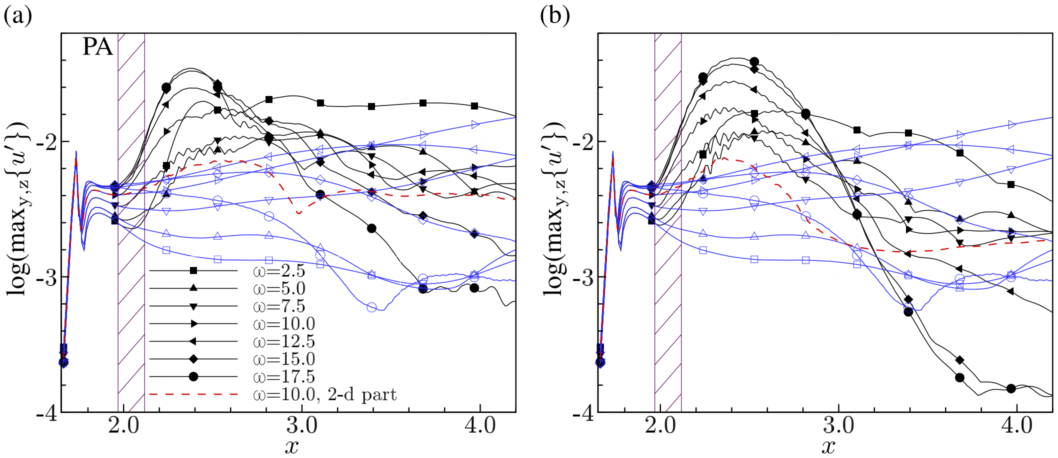

Figure 2: Downstream development of modal $u'_{(h)}$-amplitudes for (a) case Sym and (b) case NonSym from Fourier analysis in time (maximum over y and z, $2.5 \leq \omega \leq 17.5$, $\Delta = 2.5$). Open symbols denote the reference case without plasma actuation.

of the actuators by a spanwise homogeneous disturbance strip is shown in Fig. 2. Locally strong amplification of the test modes is found in the near wake of the actuators for both cases; we note that Shahinfar et al. [5] and Barckmann et al. [6] report similar findings. However, farther downstream the amplitude of the relevant modes is reduced compared to the reference case without plasma actuation and all modes are damped, yielding delayed transition to turbulence. Stronger attenuation is found for case NonSym, due to stronger three-dimensionality, despite a somewhat weaker mean-flow distortion.

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References

[1] S. Grundmann and C. Tropea. Experimental transition delay using glow-discharge plasma actuators. *Exp. Fluids*, 42:653–657, 2007.

[2] M. Kotsonis, R. Giepmann, S. Hulshoff, and L. Veldhuis. Numerical Study of the Control of Tollmien-Schlichting Waves Using Plasma Actuators. *AIAA J.*, 51:2353–2364, 2013.

[3] C. Y. Schuele, T. C. Corke, and E. Matlis. Control of stationary cross-flow modes in a Mach 3.5 boundary layer using patterned passive and active roughness. *J. Fluid Mech.*, 718:5–38, 2013.

[4] P. C. Dörr and M. J. Kloker. Crossflow transition control by upstream flow deformation using plasma actuators. *J. Appl. Phys.*, 121:063303, 2017.

[5] S. Shahinfar, S. S. Sattarzadeh, J. H. M. Fransson, and A. Talamelli. Revival of Classical Vortex Generators Now for Transition Delay. *Phys. Rev. Lett.*, 109(074501), 2012.

[6] K. Barckmann, C. Tropea, and S. Grundmann. Attenuation of Tollmien - Schlichting Waves Using Plasma Actuator Vortex Generators. *AIAA J.*, 53(5), 2015.