

# High–frequency secondary instability modelled by nonlinear PSE

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## Abstract

Crossflow–dominated laminar–turbulent transition in three–dimensional boundary layers is studied by compressible nonlinear nonlocal theory based on the parabolized stability equations (PSE). The DLR/FOI NOLOT/PSE code is used. It is demonstrated that the strongly nonlinear stages of the transition process, i.e. the formation of high–frequency secondary instabilities, their linear and nonlinear growth as well as the subsequent disintegration of the secondary disturbance structures which is accompanied by a degradation of the stationary crossflow vortices can be modelled by this type approach provided that sufficiently high resolution in modal space is used. The application of PSE is limited to convectively unstable flows. However, recent spatial direct numerical simulations (DNS) by Wassermann & Kloker (2002) clearly demonstrated the convective nature of this type of flow and thus confirmed corresponding numerical results by Koch (2002) and experimental observations by White (2000).

Figure 1 shows results for the virtually incompressible DLR swept–flat plate experiment. The basic flow parameters are identical to those used by Koch *et al.* (2000). A stationary crossflow vortex and a travelling crossflow mode were initialised close to branch I. The initial amplitudes were chosen such that the stationary crossflow vortex starts to saturate at about 60% chord and remains dominant in amplitude at all chord positions. Both initialised modes initially grow in amplitude and thus nonlinearly generate more and more higher harmonics. Further downstream these higher harmonics constitute the (high–frequency) secondary instabilities (Hein, 2005). Their typical spatial structure (see e.g. White (2000); Koch *et al.* (2000)) is shown in fig.1a. Having reached amplitudes of about one percent, these secondary instabilities start to disintegrate (fig.1b). This process is accompanied by a degradation of the stationary crossflow vortices and the appearance of small–scale vortical structures in the flow field. The travelling disturbances generate vortical structures which are winding around the primary stationary vortices, similar to the observations made by Kohama & Egami (1999).

Additional results are available e.g. for cases where the stationary crossflow vortices and the initialised travelling crossflow vortices are comparable in amplitude. A distinction between primary and secondary disturbances is not possible in this case and hence out of scope of secondary instability theory. Such a transition scenario was observed in windtunnel experiments at moderate freestream turbulence levels.

## References

HEIN, S. 2005 Nonlinear transition analysis. Research report DLR-FB 2005-10.

KOCH, W. 2002 On the spatio–temporal stability of primary and secondary crossflow vortices in a three–dimensional boundary layer. *J. Fluid Mech.* **456**, 85–111.

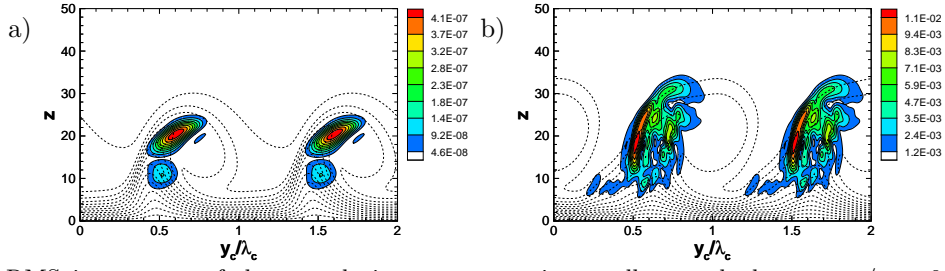


Figure 1. RMS-isocontours of the  $u_v$ -velocity component in a wall-normal plane at  $x_c/c = 0.70$  (a) and  $x_c/c = 0.90$  (b) plotted on top of the isolines (dashed) of the time-averaged velocity component in  $x_v$ -direction for a frequency of 2700 Hz ( $m=20$ ). The  $x_v$ -coordinate is locally aligned with the direction of the primary stationary crossflow vortex axis.

KOCH, W., BERLOTTI, F., STOLTE, A. & HEIN, S. 2000 Nonlinear equilibrium solutions in a three-dimensional boundary layer and their secondary instability. *J. Fluid Mech.* **406**, 131–174.

KOHAMA, T. & EGAMI, Y. 1999 Active control of instabilities in a laminar boundary layer. AIAA–Paper 99–0921.

WASSERMANN, P. & KLOKER, M. 2002 Mechanisms and passive control of crossflow-vortex-induced transition in a three-dimensional boundary layer. *J. Fluid Mech.* **456**, 49–84.

WHITE, E. 2000 Breakdown of crossflow vortices. PhD thesis, Arizona State University.