High–frequency secondary instability modelled by nonlinear PSE

By S. Hein

DLR, Bunsenstraße 10, D-37073 Göttingen, Germany

Stefan.Hein@dlr.de

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

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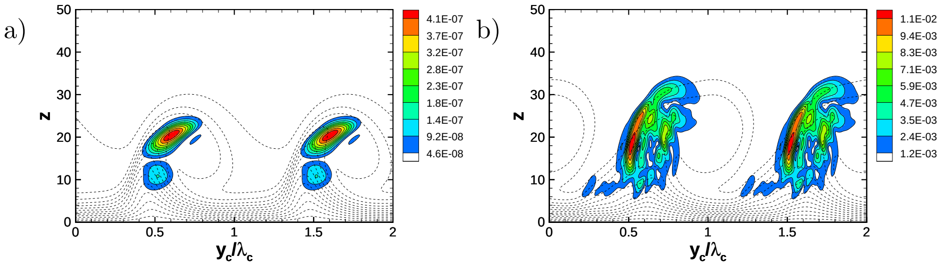

Figure 1. RMS–isocontours of the u_v–velocity component in a wall–normal plane at $x_c/c = 0.70$ (a) and $x_c/c = 0.90$ (b) plotted on top of the isolines (dashed) of the time–averaged velocity component in x_v–direction for a frequency of 2700 Hz (m=20). The x_v–coordinate is locally aligned with the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

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