Nonlinear PSE analysis of control of cross-flow disturbances in supersonic boundary layers by means of micron-sized roughness elements

C-G Unckel*, A. Hanifi†* and D.S. Henningson*

The idea of micron-sized roughness elements as a mean of control of laminar-turbulent transition in cross-flow dominated boundary-layer flows has been introduced by Saric et al[1]. Here, a cross-flow disturbance with a certain wave length, $\lambda 1$ is picked as the most likely candidate to cause transition (target). A row of micron-sized roughness is placed close to the leading edge where the cross flow modes grow fast. The spacing of the roughness corresponds to a wavelength $\lambda 2$ and will trigger the mode with this particular wave length (killer). The hope is that the non-linear interaction of disturbances will damp the target amplitude and thereby delay transition. The control mechanism is thought to be the modification of the mean flow by the vortices generated by the roughness elements.

Here, we present the numerical analysis of the control mechanism mentioned above. The work is a part of the EU-project SUPERTRAC. The pressure distribution investigated corresponds to the boundary layer over an airfoil at Mach 1.5 with a sweep angle of 30°. In this case, the cross-flow disturbances are dominant. Only the stationary modes are considered since it is assumed that those are the dominant ones at flight condition due to the low level of the free-stream turbulence.

The studies are performed using the non-linear Parabolized Stability Equations (PSE). We investigated the effects of initial amplitude and spanwise wavenumber of the killer mode on development of the target mode. A typical result is shown in figure 1. The top figure shows the linear growth of the cross flow modes. The black line corresponds to the chosen target mode (it reaches a given value of the N-factor first). The red line corresponds to the chosen wave length for the killer mode. For an efficient control, the killer mode should grow fast close to the leading edge and decay further downstream. Otherwise it could cause transition on its own. The bottom figure shows the amplitude of the killer (dashed) and target (full lines) modes normalized with the local free-stream velocity. The different start amplitudes of the killer mode represent different heights of the roughness elements. The amplitude of the target is kept the same. As can be seen, the killer mode shows a strong increase in growth with increasing start amplitudes. The effect on the target is however rather limited until high initial amplitudes for the killer are used. The problem of fast growing killers persists in other cases, too.

*KTH Mechanics OB 18, SE-100 44 Stockholm, Sweden.
†FOI, Swedish Defense Research Agency, SE-164 90 Stockholm, Sweden.
[1] Saric et al, *AIAA Paper* **98-0781**,(1998).

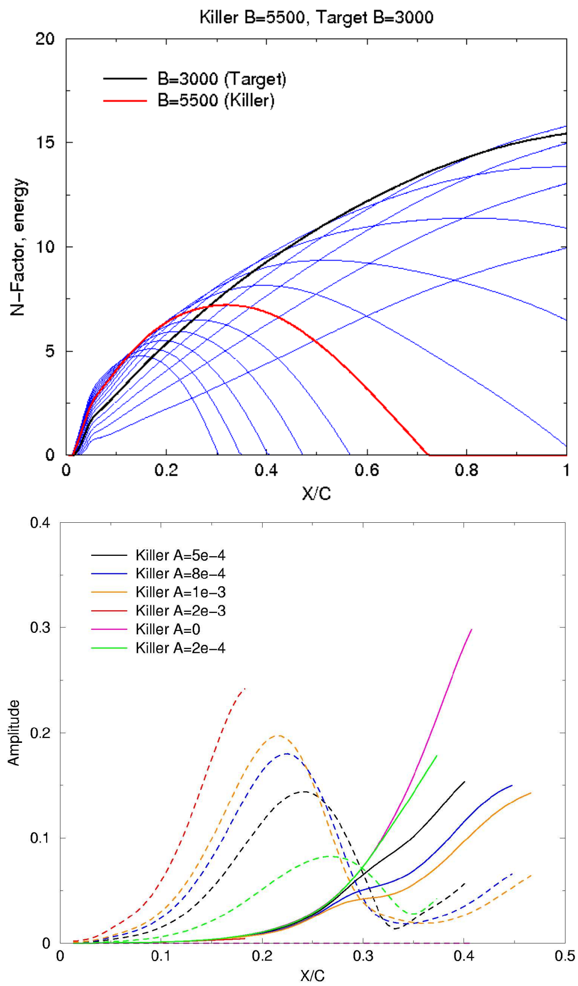

Figure 1: (Top) Linear stability analysis of stationary cross flow modes. (Bottom) Non-linear interaction between target and killer modes.