Mitteilung

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The effect of 2-D surface irregularities on laminar-turbulent transition: A comparison of numerical methodologies

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Laminar-turbulent transition prediction is of practical interest in aircraft design since transition affects important aerodynamic quantities such as drag and heat transfer. Extended laminar flow on aerodynamic surfaces is an effective way of reducing aircraft drag. One of the major challenges for the implementation of laminar-flow surfaces is the potential for any irregularity to move transition upstream. Under low-disturbance environment, boundary-layer transition results from the growth and breakdown of different flow instabilities. In 2-D flows the scenario is dominated by Tollmien-Schlichting (TS) instabilities. Common wing-surface irregularities, such as two-dimensional steps, gaps or waviness can alter the growth characteristics of TS waves and therefore must be taken into account at the design stage.

The effect of steps, gaps and humps on the development of TS waves in an incompressible boundary layer has been investigated in [1] using direct numerical simulations (DNS). All the irregularities were found to have an overall destabilizing effect. In the present work, we compare those results with Local Stability Theory (LST), Parabolized Stability Equations (PSE) and Adaptive Harmonic Linearized Navier-Stokes (AHLNS) approach. In the past, LST and PSE, together with the e^N method, have been successfully applied for transition prediction in cases without surface irregularities where the local streamwise flow gradients were small. However, the validity of the assumptions of such methods becomes questionable with the increased gradients locally induced by the surface irregularities. AHLNS removes some of the inherent limitations present in LST and PSE, and it has been already applied effectively in the presence of humps by Franco et al. [2]. Edelmann et al. [3] used LST with forward-facing steps introducing a special treatment for the region around the step and Park et al. [4] performed PSE analyses for smooth humps. To the best of the authors' knowledge, there is no published comparison between LST, PSE, AHLNS, and DNS for the development of TS waves encountering surface irregularities.

Fig. 1 shows the steady laminar base flow for one of the surface imperfections studied: a smooth hump. For this case, the comparison between LST, PSE, AHLNS, and DNS for the development of TS waves is given in Fig. 2 for a selected frequency. TS waves are destabilized in the decelerated region on the leeward side of the hump where they also interact with the separation bubble. A perfect agreement between DNS and AHLNS is observed. The LST and PSE results exhibit differences in the hump region, before recovering the same growth rate far downstream. Moreover, LST is already underpredicting the decay in the stable region upstream of the hump. This behaviour was also noticed for the flat plate. For the frequency considered the TS wavelength is twice the width of the hump and therefore the applicability of PSE would be dubious. The characteristic length scale of the perturbation in the streamwise direction is of the same order as the corresponding characteristic length scale of the streamwise flow variation induced by the surface irregularity. For LST the basic state is approximated as locally parallel, an assumption that does not hold, in particular in the vicinity of the hump. Under these circumstances LST should be used with caution. In the final paper the above results will be complemented by other type of irregularities taken from [1], including surface discontinuities that induce a stronger local distortion of the boundary-layer compared to the smooth hump. The results will be discussed with particular emphasis on the applicability of the LST, PSE and AHLNS methodology and their comparison with DNS.

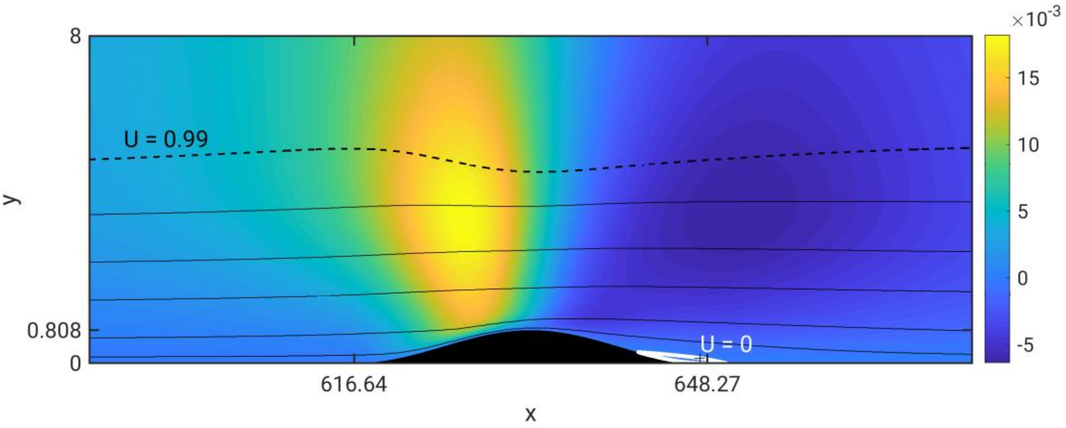

Figure 1: *Coloured contours of the non-dimensional wall-normal velocity component (V) and iso-lines (black lines) of the non-dimensional streamwise velocity component (U) for the base flow with a smooth hump computed by means of DNS (see Tocci et al. [1]). The white line indicates the iso-line of zero streamwise velocity. The axes are not to scale.*

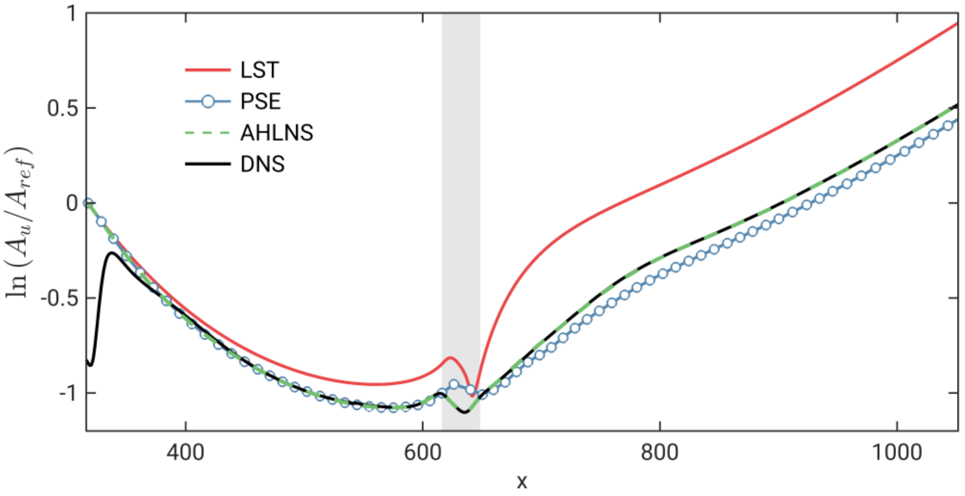

Figure 2: *Natural logarithm of the normalized disturbance amplitude ($A_u(x) = \max_y|u(x,y)|$) for a TS wave of dimensionless reduced frequency $F = 49.34 \times 10^{-6}$. The grey area indicates the location of the smooth hump.*

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References

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