Mitteilung

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Influence of surface irregularities on the expected boundary-layer transition location on hybrid laminar flow control wings

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Introduction

Hybrid laminar flow control (HLFC) wings have captured the interest of several research projects, in particular the HLFC-WIN project [1], because of the potential of suction for reducing drag on commercial aircraft [2]. This reduction in drag is mainly due to the impact on laminar-turbulent transition, extending the region along the wings where the flow remains laminar. Typically, on HLFC wings, suction is applied only in the leading edge region (before the front spar). The flow suction modifies the boundary-layer (BL) profiles in such a way that the growth of flow instabilities that might trigger the above mentioned laminar-turbulent transition location, e.g. Tollmien-Schlichting (TS) waves or crossflow (CF) vortices, is delayed. However, the joint between the leading edge suction panel and the wing box may introduce surface irregularities (e.g. backward/forward-facing steps (BFS/FFS), gaps, etc.) that might enhance the spatial development of those flow instabilities and, therefore, reduce the potential benefit of the suction system [3]. For this reason, it is crucial during the design process to quantify the influence of such surface irregularities in terms of BL instability.

Methodology

The Adaptive Harmonic Linearized Navier-Stokes (AHLNS) approach [4], in combination with the Parabolized Stability equations (PSE) [5], offers the most efficient way to compute the effect of surface irregularities on the spatial development of convective instabilities, e.g. TS waves and CF vortices, in terms of n-factor curves [6]. The PSE are applied far from the location of the surface irregularity, where the streamwise variations of the base flow quantities remain small (w.r.t. wall-normal gradients). The AHLNS methodology is used in the vicinity of the irregularity, where the assumption of small variations of the streamwise variables is no longer valid. The efficiency of the AHLNS approach, in comparison with other standard methodologies as Direct Numerical simulations (DNS), lies in the “wave-like” character assumed for describing the convective instabilities, in a similar fashion as PSE. This assumption significantly reduces the number of streamwise grid points required in comparison with DNS computations [7], allowing parametric studies for transonic wings at high Reynolds numbers.

Results

In the present work, we concentrate on the influence of surface irregularities on the expected BL transition location. In order to reduce the large number of parametric studies, certain quantities remain fixed, e.g. suction flow-rate distribution, Mach number, Reynolds number and streamwise location of the surface irregularity. The parametric study focuses on the type of surface irregularity (gap, BFS, FFS), its height (0.2-0.8 mm) and length (1-3 mm). As an example, Figure 1-a) shows the baseflow streamwise velocity contours and sectional streamlines for a BFS of 0.2 mm height placed at 20% chord. Although the step height is relatively small (~25% of the BL displacement thickness), the length of the recirculation area is about 7 mm. Figure **1**-b) depicts the spatial evolution of a particular incoming TS wave for the same BFS, computed with AHLNS.

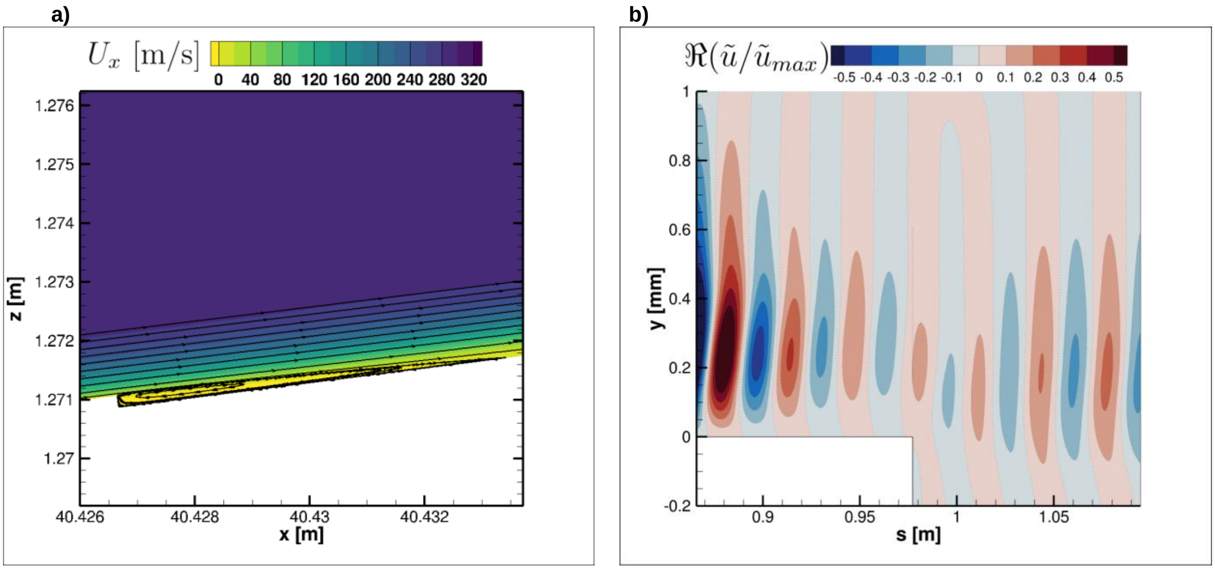

Figure 1. a) Streamwise velocity contours and sectional streamlines for a BFS of 0.2 mm height placed at 20% chord in global coordinates (x,z) [axes are to scale]; b) Real part of the streamwise velocity disturbance $\Re(\tilde{u}/\tilde{u}_{max})$ for an incoming TS wave of frequency f = 3141 Hz and spanwise wavenumber β = 105 m^{-1} at an arbitrary instant of time for a BFS of 0.2 mm height placed at 20% chord in body-attached coordinates (s,y) [axes are not to scale].

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