On K-Type Transition in Swept Wing Boundary Layer in the Presence of an Acoustic Field

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Understanding and controlling laminar-turbulent transition in Three-Dimensional (3D) boundary layers remain so far unsolved problem in fluid dynamics and its applied applications. There still exist various unknown transition scenarios because of complexity of phenomenon underling the breakdown of laminar flow to turbulent stage [1]. In order to study the generation and evolution of the viscous eigen-waves in 3D swept wing boundary layers experiments have been performed in a low turbulence level wind tunnel L2 at the department of Thermo and Fluid Dynamics in Chalmers University of Technology, Gothenburg, Sweden.

Figure 1. Photo of the airfoil in the wind tunnel

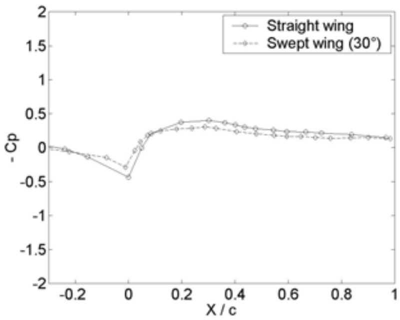

Figure 2. Distribution of the pressure coefficients

The linear and nonlinear evolution of growing travelling waves have been measured in all three directions (X,Y,Z) in the swept wing boundary layer by a single, constant temperature hot-wire. Preliminary experiments were conducted with an airfoil model at several sweep angles (0, 30 and 45 degrees). The existing traverse system has been improved in order to study essentially three-dimensional flows in transversal direction (a spanwise coordinate was added to streamwise and vertical axes). Experimental set-up and the 3-axis traverse system used are shown in figure 1. The main series of experiments were conducted with model set at two different sweep angles, namely, at zero sweep angle (straight wing configuration) and 30 degrees (swept wing configuration). The pressure coefficient distributions over the airfoil in streamwise direction for both configurations are shown in figure 2. At the chord region X/c= 0.30, where the pressure gradient changed its sign from negative to positive, the roughness elements were placed in order to create weak spanwise periodicity of initially two-dimensional wave front. The roughness array consists of 10 circles (7.5 mm diameter and 0.19 mm height) aligned along the leading edge with spacing of 15 mm. All experiments were performed at a free stream velocity of 12.8 m/sec.

The quality of the subsonic low turbulence level wind tunnel has been scrutinized. It has been found out that the wind tunnel has met all requirements needed for performing such experiments. Only one minor feature about the flow quality were observed, namely, rather high level of an acoustic field in the wind tunnel test section, which is generated by the motor or/and the steering system. Nevertheless, this acoustic field has been used in our experiments as the “artificial” disturbance source. It should be noted that at linear stage the fundamental central frequency peak at 300Hz corresponds to the most energetic acoustic mode. To map the flow patterns in the disturbed boundary layer the measurements were triggered with these acoustic disturbances.

The main result of present experimental investigation can be summarized as follows:

One of the most significant results obtained is the following: for the best of our knowledge the new K-type transition has been found in the boundary layer over a swept wing. Thus, natural laminar-turbulent transition over an aircraft’s wing has been simulated and studied in control manner. The crossflow was found to play an essential role in nonlinear stages of transition. Amplitude frequency and spanwise wavenumber spectral decompositions of the flow patterns were found to be similar for both zero and 30 degrees of sweep. Nevertheless, because of the different phase spectra, due to the crossflow, the temporal-spatial structures of the disturbed flow field over swept wing have revealed significant differences in K-type transition to turbulence (see figure 3).

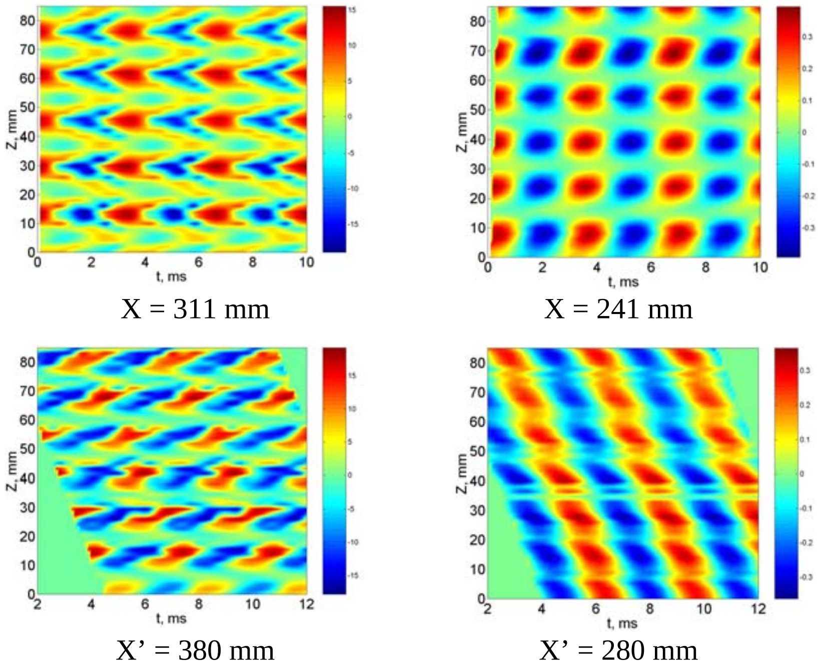

Figure 3. Two scenarios of K-type transition observed over an airfoil. The top row presents evolution over straight wing, whereas the bottom row reveals K-type of breakdown observed in swept wing configuration (sweep angle = 30). The flow direction is from right to left.

The main feature of the non-linear evolution is that the crossflow results in breakdown of symmetry of so-called lambda structures [2].

References

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2. Kozlov V.V., Levchenko V.Y. & Saric W. S., 1983 “Formation of three-dimensional structures in a boundary layer at transition,” *Preprint No. 10-83. Inst. Theoret. Appl. Mech., USSR (in Russian)*