Mitteilung

Fachgruppe: Turbulenz und Transition

Near-wall dynamics of laminar separation bubbles at low inflow turbulence intensities

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Laminar separation bubbles (LSB) form at aerodynamically low Reynolds numbers (Re_c) due to adverse pressure gradients that induce flow separation. In the free shear layer, the Kelvin-Helmholtz instability mechanism amplifies perturbations until their amplitudes reach such a high value that vortices are formed. The momentum entrainment of the transitional flow can force a reattachment. The unstable flow causes variations in drag, pitch and lift, which can be detrimental to the efficient operation of Unmanned Aerial Vehicles (UAV), gliders, and small to medium sized turbine blades. Studying the phenomenon experimentally is challenging, due to its relatively small size, surface curvature of foils and its sensitivity to chaotic or deterministic disturbances. Non-invasively analyzing an LSB from the near-wall perspective can be achieved by applying an artificial heat-flux on a surface and studying the footprints of coherent structures in the thermal field with infrared thermography or temperature sensitive paint (TSP), provided the natural convection does not greatly influence the flow. The aspect of the low bubble height and surface curvature can thus be circumvented and near-wall flow information can be accessed with a level of detail that can be provided only by numerical simulations.

The Tollmien-Schlichting and the Kelvin-Helmholtz instability behavior can be accurately predicted by solving the Orr-Sommerfeld equation or, in the case of inviscid flows, the Rayleigh equation (Schlichting and Gersten (2017)) up until the influence of the non-linear terms cannot be neglected anymore. The secondary instabilities that cause the degradation of the Kelvin-Helmholtz roll-up vortices can not only define the spanwise and streamwise vorticity content in the aft portion of an LSB but also that of the turbulent boundary layer (Zhang et al. (2009)). Which secondary instabilities are responsible for the coherent structure deformations has been shown to depend on the free-stream turbulence level (Jones et al. (2008)) and their influence is far more complicated to predict and must thus be simulated or experimentally analyzed. Although knowledge of the free-shear and higher regions of the boundary layer is abundant, most studies that provide detailed insight of the most complex near-wall flow mechanisms at low turbulence levels stem from numerical simulations. The purpose of the present study is to assess which coherent structures impact the surface of a foil in the low turbulence environment provided by a towing tank. An artificial heat flux is created by spraying electrically conductive paint onto a groove milled on the suction side of an SD 7003 foil (see figure 1). The thermal footprints are visualized by using Europium based TSP and the single-shot lifetime method. The influence of the heat flux on the transition behavior is assessed using 2D2C-PIV to be nearly non-existent.

The experiments are conducted at Re_c=6·10^4 and 8·10^4 and an angle of attack of α=6°. The applied heating power at the lower Re_c is 1764 W/m^2 and 2545 W/m^2 at the higher. Spectral proper orthogonal decomposition (SPOD) analysis of the thermal fluctuations displays the footprints of the Kelvin-Helmholtz instabilities with temporary high levels of span-wise coherence (see figure 2). Instantaneous thermal snapshots display the propagation of simultaneously emerging V-shaped footprints in the stream-wise direction. Examples are depicted in figure 3. Some of the snapshots depict span-wise coherent footprints, which can only be assumed to be caused by Kelvin-Helmholtz vortices, in the same region as the V-shaped footprints, which implies that these are two distinct phenomena. Quasi-simultaneous PIV and TSP measurements confirm the assumption.

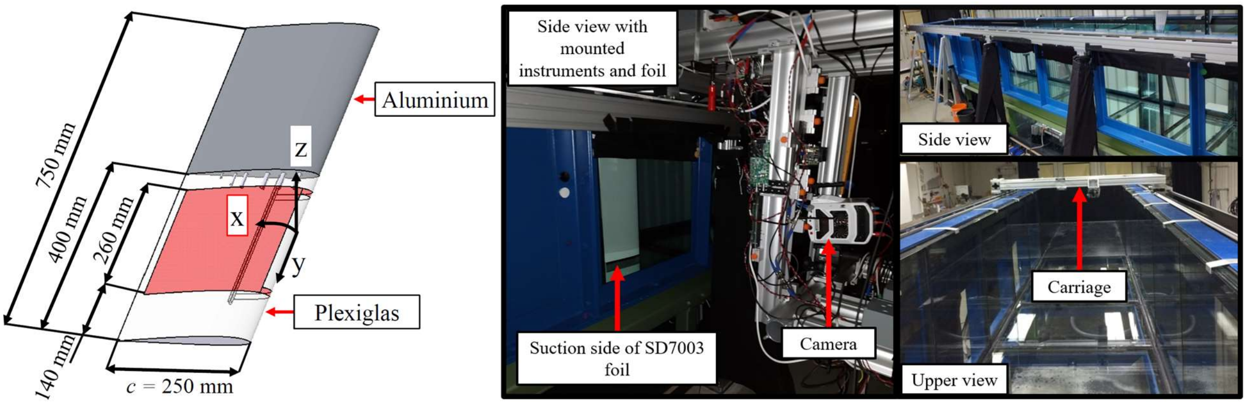

Figure 1. Left: CAD model of the SD-7003 foil equipped with the heating element (red region). Right: Images depicting the towing tank and the experimental setup for the TSP measurements. The foil is mounted vertically in the tank.

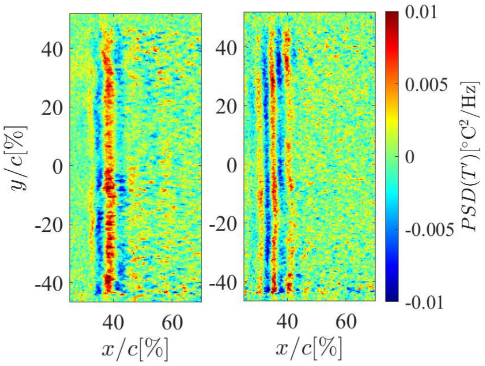

Figure 2. First SPOD mode spatial reconstruction at a frequency of 6.25 Hz at Re_c=6·10^4 (left) and 12.81 Hz at Re_c=8·10^4 (right)

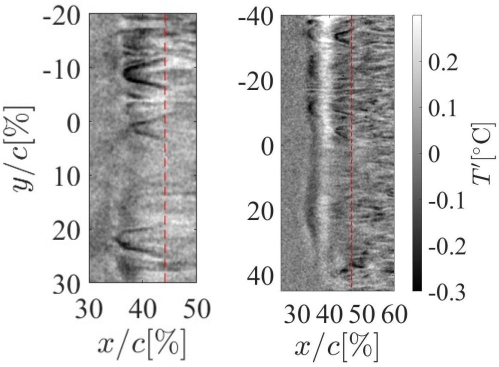

Figure 3. High-pass filtered temperature snapshots at Re_c=6·10^4 (left) and Re_c=8·10^4 (right). The red lines indicate the time averaged reattachment location

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