Investigation of Shock-Induced Boundary-Layer Transition in Transonic High Reynolds Number Flows Using Temperature-Sensitive Paints

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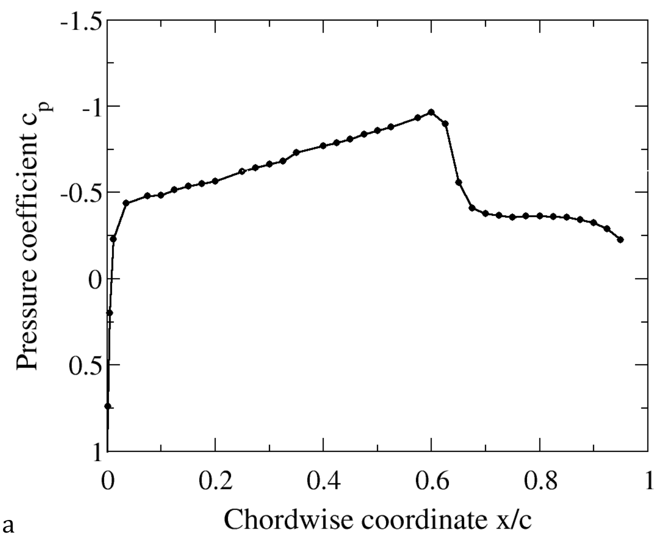
Abstract On laminar and supercritical wings at transonic flow conditions and chord Reynolds numbers up to approximately 20 million, shock-wave / boundary-layer interaction can be involved in the transition process leading the laminar boundary layer to turbulence. At small angles of attack, transition over the suction side of the wing is likely to be induced by a shock terminating a supersonic flow region, which is developed by the accelerated boundary layer on this side of the wing. In the present work, shock-induced boundary-layer transition was experimentally studied on laminar and supercritical airfoil models via temperature-sensitive paints. The investigations were carried out at freestream Mach numbers up to 0.8 and showed characteristic features of shock-wave / boundary-layer interaction in transitional boundary layers at high Reynolds numbers.
Keywords: Shock-Wave / Boundary-Layer Interaction, Transition, Temperature-Sensitive Paint

Shock-wave / boundary-layer interaction (SWBLI) is a complex phenomenon occurring in a variety of flows [1]. On laminar and supercritical wings at transonic flow conditions and chord Reynolds numbers up to approximately $Re_c = 20 \cdot 10^6$, SWBLI can be involved in the transition process leading the laminar boundary layer to turbulence. At small angles of attack (typically below AoA = 1.5°), the laminar boundary layer over the suction side of the wing is accelerated, and therefore stabilized [2], for a significant portion of the wing chord length. This is shown by the example pressure distribution in Fig. 1a, measured on a two-dimensional natural laminar flow (NLF) airfoil model [3][4] at M = 0.8, $Re_c = 8.2 \cdot 10^6$ and AoA = 0.9°, where M is the freestream Mach number. The experiments were conducted in the Cryogenic Ludwieg-Tube Göttingen [4]. At these transonic flow conditions, the supersonic flow region was terminated by a shock that interacted with the boundary layer; in particular, the abrupt pressure increase induced the formation of a laminar separation bubble, and the foot of the shock had a characteristic λ-structure [5].



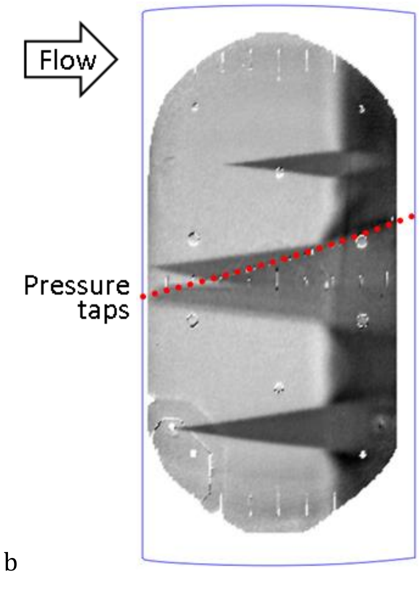


Fig. 1 Pressure distribution (a) and corresponding TSP result (b) on the upper side of an NLF airfoil model [3][4] at M = 0.8, $Re_c = 8.2 \cdot 10^6$ and AoA = 0.9°

Transition occurred within the laminar separation bubble and was investigated in the present work by means of the Temperature-Sensitive Paint (TSP) measurement technique [3][6]. In a manner analogous to other thermographic methods, such as infrared thermography, boundary-layer transition was detected by measuring the temperature change from the laminar to the turbulent regime. This is shown in Fig. 1b for the test conditions of Fig. 1a. In Fig. 1b, the flow is from the left; laminar and turbulent regions correspond to bright and dark areas, respectively. Regions with too low signal-to-noise ratio were white-masked.

The TSP result shows that, in regions sufficiently distant from the observed turbulent wedges, the shock-induced transition front was an essentially straight line in the spanwise direction. Transition was detected in these regions at chordwise locations between x_T/c = 68.5 % and 72.5 %. This difference was probably due to the three-dimensional SWBLI occurring at the examined test conditions even for a nominally two-dimensional freestream. The brighter strip observed in the TSP result immediately upstream of the transition location was very likely the thermal signature of the laminar separation bubble [7] below the λ-structure. The SWBLI appears to be particularly complex in the regions between the shock-induced transition front and the turbulent wedges. These arose from disturbances originating from the pressure taps in the leading-edge region, from localized surface roughness and from model surface contamination during wind-tunnel operation. Note here that one turbulent wedge caused by model contamination affected the measurement of the surface pressure distribution at $x/c > 30$ %: the pressure distribution downstream of this location was thus more similar to a turbulent rather than to a transitional one.

Further results of SWBLI in transitional boundary layers, obtained on NLF and supercritical airfoil models at transonic flow conditions and high Reynolds numbers, will be presented at the *15th International Conference on Fluid Control, Measurements and Visualization*.

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