Bump-Induced Transition in Compressible High Reynolds Number Flow: Experimental Results and Correlation with Linear Stability Analysis

Introduction Surface bumps can occur on aircraft components (e.g., at or between structural joints, ribs and stringers) and can induce a marked amplification of boundary-layer instabilities, thus leading to premature transition to turbulence. The influence of bumps on boundary-layer transition was systematically studied in combination with the effect of variations in the following parameters: streamwise (global) pressure gradient, freestream Mach number (up to $M = 0.77$) and chord Reynolds number (up to $Re = 10 \cdot 10^6$). The experimental investigations were conducted in a (quasi-) two-dimensional flow in the Cryogenic Ludwig-Tube Göttingen (DNW-KRG).

Wind-tunnel model BuLASTra

- Leading edge at the bottom of the image
- Model chord $c = 200$ mm, bump crest at $x/c = 45\%$
- Temperature-Sensitive Paint (TSP) for transition detection

Bump shape

Numerical setup

- Laminar basic flow computed with boundary-layer code COCO using the experimental pressure distributions and considering an isothermal wall.
- Approach applicable only for cases without separation, i.e. mostly the reference and small bump configurations.
- Compressible linear local stability analyses (LST) using both LILLO and NOLOT.

Effect of the variation of the streamwise (global) pressure gradient ($\beta_H$)

Experimental results (TSP)

- $\beta_H = 0.063$
  - $x_T/c$ (small) $\sim 62\%$
  - $x_T/c$ (big) $\sim 48\%$
- $\beta_H = 0.096$
  - $x_T/c$ (small) $\sim 78\%$
  - $x_T/c$ (big) $\sim 49\%$

Transition location $x_T/c$ shown by dashed yellow lines

- Boundary-layer transition location moved upstream with increasing bump height.
- In the case of the small bump, transition was very sensitive to the global pressure gradient $\beta_H$.
- With the mid bump, the transition sensitivity on $\beta_H$ depended on Mach and Reynolds numbers.
- Transition induced by the big bump was essentially unaffected by $\beta_H$.

Numerical results (N-factors)

- Correlation of the experimental data with results from LST for the small bump configuration:
  - Transition N-factors $N_T$ decreased with increasing $M$ and increasing $\beta_H$.
  - The decrease of $N_T$ with increasing $M$ may be related to the increasing level of total pressure fluctuations in DNW-KRG.
  - In some cases, the transition locations found in the experiments could not be explained via the adopted $e^N$-methodology.