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The interaction between an isolated roughness element and free-stream turbulence

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Control and delay of the laminar-turbulent transition is a key parameter in reducing skin friction and drag. The flow characteristics, surface roughness, and environmental noises can affect the onset of transition. The experimental work by Klebanoff & Tidstrom [1] showed that the natural transition can be promoted with the spanwise-invariant roughness elements. The aim of the present work is to study the interaction of the free-stream turbulence (FST) and an isolated cylindrical roughness element and its impact on the transition onset in a flat-plate boundary layer. To this end, high-fidelity numerical simulations and experimental measurements are performed. Using the spectral-element solver Nek5000, direct numerical simulations are performed for the roughness element immersed in the boundary layer over a flat plate with an asymmetrical leading edge, with and without FST. The FST intensity is 2.2%, and the integral length scale is approximately 13 millimeters at the leading edge. The Reynolds number based on the roughness height and the corresponding velocity at that height is $Re_{kk} = U_k k/\nu \approx 244$. In the simulations, the FST with a similar spectrum to the one in the experiments is generated by superimposing a number of Fourier modes at the inflow boundary.

The initial numerical and experimental results show that in the absence of FST, for the chosen flow parameters, high- and low-speed streaks are generated downstream of the roughness element while the flow remains laminar. The global stability of the flow is confirmed through an impulse response analysis. When FST is added, the spanwise spacing of the streaky structures changes and the transition location of the boundary layer moves upward. One of the main goals of the present study is to investigate the relation between the size of the roughness element and the aspect ratio of the streaky structures. To identify the structures behind the roughness element and study their instability in the presence of FST, stability, and proper orthogonal decomposition (POD) analyses are considered. Our numerical results are compared to the hot-wire anemometry measurements that are performed in the Minimum Turbulence Level (MTL) wind tunnel at KTH.

REFERENCES

[1] Klebanoff P. S. and Tidstrom K. D., Mechanism By Which A Two-Dimensional Roughness Element Induces Boundary-Layer Transition: Roughness Induced Transition. *Phys. Fluids*, 1972.