Parametric study on the effects of cylindrical cavities on transition in the Falkner-Skan-Cooke boundary layer

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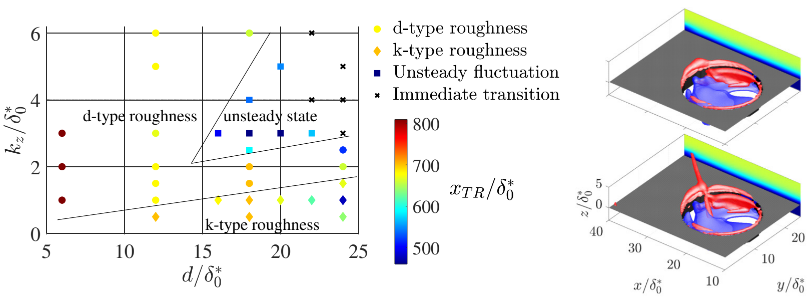
Crossflow instability is responsible for the laminar-to-turbulent transition observed in swept wings and swept flat plates near their leading edge. This instability generates crossflow vortices that grow, saturate, and ultimately collapse into turbulence. Our study focuses on the Falkner–Skan–Cooke (FSC) boundary layer, which is characterized by dominant crossflow instability throughout its extent. Using this as our base flow, we conducted direct numerical simulations to investigate the turbulent transitions induced by cylindrical cavities. Figure 1(a) illustrates the results of our parametric studies on the cavity diameter (d) and depth (k_z), which are non-dimensionalized by the inlet displacement thickness (δ_0^*). In d-type roughness, where there is no reattachment, the transition point (x_{TR}) is primarily dependent on the cavity diameter. In contrast, k-type roughness, which features reattachment on the bottom wall, exhibits more complex transition point modulations owing to factors such as cavity shape, velocity shear in the internal flow, and reattachment position. At large diameters and depths, we observed unsteady fluctuations and vortex shedding from the cavity edge (Figure 1(b)), with frequencies similar to those of the traveling wave modes in the FSC boundary layer[1]. This phenomenon is akin to an experimental observation for backward-facing steps[2], suggesting that the flow characteristics in large cavities are similar to those of 2D steps. The immediate transition near the cavity is caused by the interaction of unsteady fluctuations from the periodic array of cavities, and this state is classified as an unsteady state, as shown in Figure 1(a). In our talk, we will discuss the mechanisms underlying the modulation of the flow field characteristics.



(a) (b)

Figure 1: (a) State map of flow field and transition position. (b) 3D visualization of the region around the cavity with $k_z/\delta_0^* = 3$, $d/\delta_0^* = 16$. Iso-surfaces are vortex structure (red) and $u/U_0 = 0$ (blue). The bottom figure is $39\delta_0/U_0$ after the top figure.

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