Influence of the ratio of boundary layer thickness to roughness height in the turbulence transition caused by spatially localized disturbances

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Spatially localized disturbances can trigger early laminar-turbulent transition in boundary layer flows. This significantly influences the drag and lift of aerodynamic surfaces, as well as the heat exchange with the environment. Using infrared thermographic flow visualisation, it is possible to detect the signature of such localized disturbances by analysing the convective heat transfer caused by their wake. This suggests the possibility of creating inverse models to infer the type of disturbances present at damaged wind-turbine blades in-situ, by analysing the temperature field obtained with infrared thermography. However, to develop such an inverse model, it is crucial to first understand the influence of geometric properties at different flow conditions on the transition process and the related heat transfer. We here address this problem with direct numerical simulations (DNS).

The most important parameter of the system is the roughness Reynolds number, $Re_k = u_k k/\nu$, where k is the height of the disturbance element, u_k the velocity of the undisturbed boundary layer at height k at the streamwise position of the element and ν the kinematic viscosity of the fluid. The critical Re_k at which the disturbance destabilizes the laminar boundary layer, varies significantly depending on multiple factors like the shape and aspect ratio of the disturbance element. While this have been investigated in detail, the influence of the ratio of the boundary layer thickness to the height of the disturbance element, δ^*/k, is not well understood, and is examined here for a cubical element. The three-dimensional disturbed boundary layer flow is computed with DNS at subcritical and supercritical Re_k employing a spectral-element formulation[1]. We analyse the flow field, wall shear stresses and heat transfer for disturbance elements fully embedded in the boundary layer, protrude from it and in the intermediate regime.

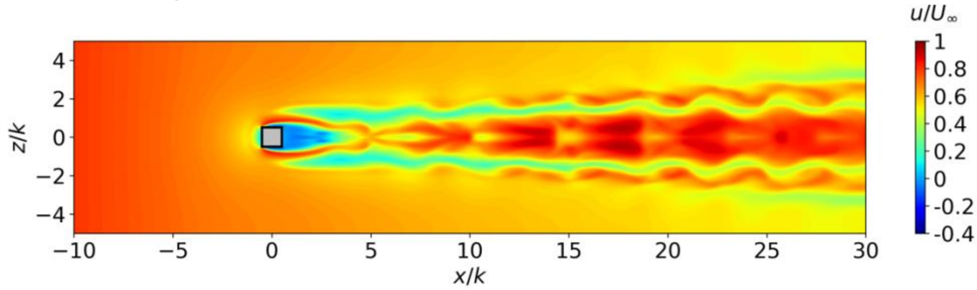

Figure 1: Streamwise velocity u/U_∞ around the disturbed boundary layer at wall normal distance $y = 0.5k$, for a cubic disturbance element at $Re_k = 600$.

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