Receptivity of three-dimensional boundary layer to small-scale free-stream turbulence (FST): distortion of FST and its impact on a flat-plate boundary layer in a contracting stream

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Motivation & application for industry

To elucidate the mechanism and process by which FST generates travelling-wave vortices in a three-dimensional boundary layer. This will have important impact in understanding cross-flow receptivity. As a necessary first step, we analyze how FST is distorted by the mean strain rate of a contracting flow with finite streamwise pressure gradient.

Research

We use Rapid-distortion theory (RDT) to model the linear interaction between FST and the non-uniform strain field. The Wiener-Hopf (WH) technique is used to calculate scattered component of the unsteady slip velocity. The total slip velocity is then used as upstream input to a viscous boundary layer calculation.

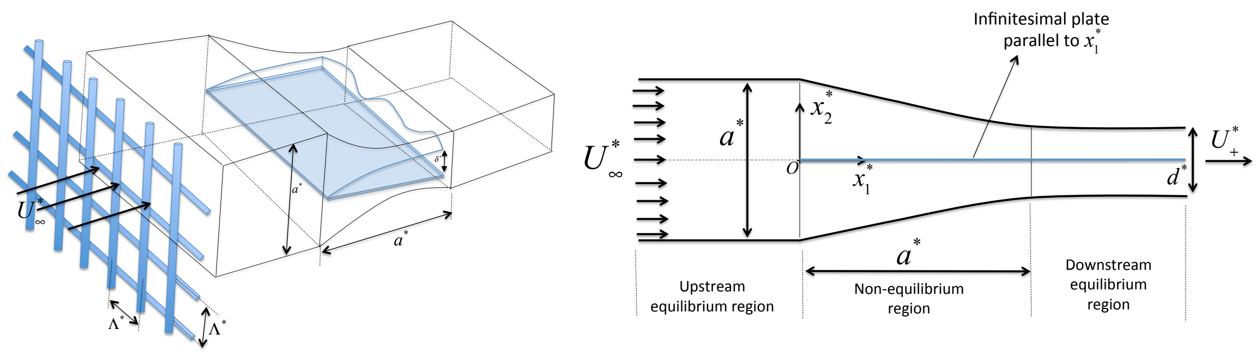

Figure 1. Receptivity of a flat plate boundary layer in a curved channel due to free stream turbulence.

Since the interaction is linear, RDT/WH analysis shows the total slip velocity at a streamwise location near the leading edge of the flat plate, $x_1 = l$, is given by the sum

$$u_1(l,0,x_3,t) = u_1^g(l,0,x_3,t) + \frac{\partial \phi^s}{\partial x_1}(l,0,x_3,t)$$

where u_1^g is the streamwise component of the quasi-homogeneous Batchelor & Proudman (1954) solution in the non-equilibrium region shown above; ϕ^s is the scattered solution that satisfies discontinuous streamwise boundary conditions on plate surface and upstream extension.

Current status: Constructing an appropriate mean flow to numerically calculate slip velocity to use in boundary layer calculations.