Role of the obliquity angle on the perturbed cross-flow boundary layer

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We propose a linear investigation on the transient dynamics of arbitrary 3D perturbations acting on the Falkner-Skan-Cooke cross-flow boundary layer. The stability of this kind of flow has been recently analyzed using modal theory [1], in the context of receptivity and transient optimal perturbations [2, 3], and experimentally. Works on optimal perturbations [3] usually consider obliquity angles in the neighborhood of a fixed value, while Breuer and Kuraishi [2] investigated the direction of the waves, but varying simultaneously ϕ and k. Here, we consider the 3D perturbative problem, expressed through the initial-value problem formulation [4, 5], by paying particular attention to the role of the obliquity of the perturbation with respect to the base flow direction. Evidence is found of counterintuitive dependency of the transient and asymptotic behavior on the travelling waves obliquity with respect to the base flow. Examples of this non-trivial behavior are reported in Fig. 1, where the evolution of the normalized energy, G(t), is displayed for three different obliquity angles (ϕ=0, π/4, π/2). Panel (a) shows there can be instability even at very low Reynolds numbers (Re=100) if the pressure gradient is sufficiently large (β=-0.1988). Panels (b) and (c) present, at a higher Reynolds number (Re=5000), configurations with a favorable (β=1) and an adverse (β=-0.1988) pressure gradient, respectively. In the favorable situation (panel b), the instability is damped by decreasing the obliquity angle, ϕ. In the adverse condition (panel c), instead, the longitudinal and orthogonal waves are amplified, while the oblique perturbation (ϕ=π/4) is damped. This result is unexpected because if the longitudinal wave is unstable, there is usually a progressive tendency to stability toward the orthogonal direction, or viceversa. Here, the intermediate wave only is stable, while the two extreme values of the obliquity angle lead to instability.

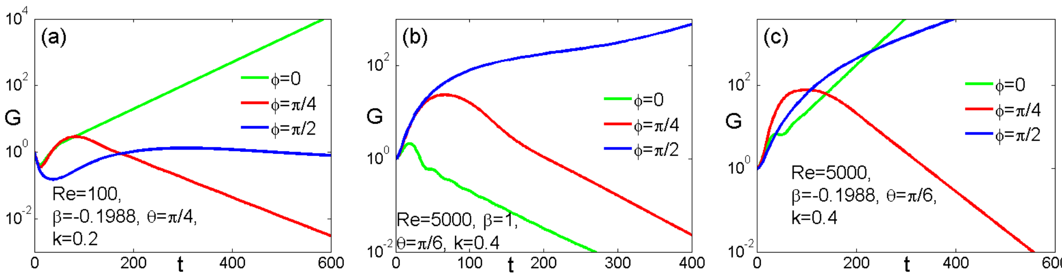

Fig. 1. Role of the obliquity angle, ϕ. Temporal evolution of the normalized energy, G(t). θ is the cross-flow angle between the streamwise and the chordwise directions, k is the polar wavenumber.

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