Instabilities in boundary layers featuring a strong localised viscosity gradient

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Recent works on the hydrodynamic stability of supercritical fluids have revealed the existence of a new unstable mode in boundary layer flows[1]. This mode was found unstable in the inviscid limit and linked to the presence of a generalised inflection point resulting from the peculiar properties of these fluids[2]. In the viscous regime, results suggest that other destabilisation mechanisms are at play as larger growth rates are observed for finite Reynolds numbers. However, no physical interpretation has yet been given for this regime. The present work aims at gaining further understanding on this matter by analysing the stability of a simpler problem and focusing on the role of viscosity. A boundary layer developing over a heated flat-plate is considered. While density is assumed constant, viscosity is chosen to vary with temperature following a hyperbolic tangent law. This generates two regions of nearly constant but different viscosities in the base flow that are connected by a region with a strong viscosity gradient. Three parameters control the amplitude, the length scale and the location of this viscosity gradient in the flow (noted y_m). Linear stability calculations are carried out, identifying different regimes of instability according to the value of y_m. Two distinct unstable Tollmien-Schlichting (TS) waves are identified, each of them being associated with one region of constant viscosity. When the viscosity gradient is further localised, an additional unstable mode appears, characterised by shorter wavelengths. Compared to TS waves, its structure is concentrated in the neighbourhood of y_m (figure 1). We show that this instability is different from those developing in two-fluid shear flows that feature a viscosity jump across their interface[3], as viscous stresses do not produce a positive work. Instead, we find that the energy transfer between the base flow and the perturbations is driven by the mean shear. The analysis of the complex phases sheds light on the associated mechanism.

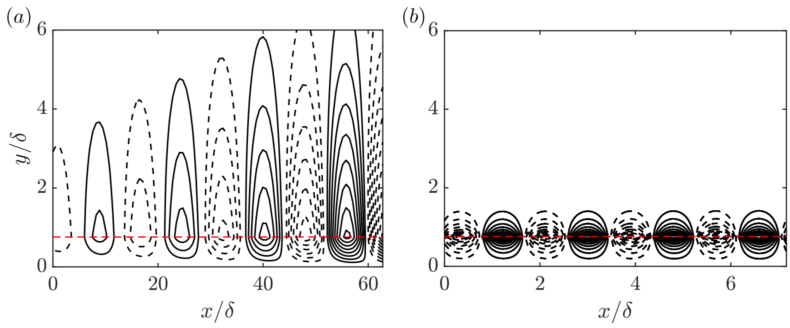

Figure 1: Contours of the stream function of the slow TS wave (a) and the additional mode with shorter wavelengths (b). The red dashed line indicates the location of y_m.

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[1] Ren *et al.*, *J. Fluid Mech.* **871**, 831–864 (2019).
[2] Bugeat, *arXiv*:**2211.04935** (2022).
[3] Yih, *J. Fluid Mech.* **27**, 2 (1967).