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Modal and non-modal evolution of perturbations for parallel round jets

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The present work investigates the local modal and non-modal stability of round jets for varying aspect ratios \( \alpha = R/\theta \), where \( R \) is the jet radius and \( \theta \) the shear layer momentum thickness, for Reynolds numbers ranging from 10 to 10,000. The competition between axisymmetric (azimuthal wavenumber \( m = 0 \)) and helical (\( m = 1 \)) perturbations depending on the aspect ratio, \( \alpha \), is quantified at different time horizons. Three different techniques have been used, namely, a classical temporal stability analysis in order to characterize the unstable modes of the jet; an optimal excitation analysis, based on the resolution of the adjoint problem, to quantify the potential for non-modal perturbation dynamics; and finally an optimal perturbation analysis, focused on the very short time transient dynamics, to complement the adjoint-based study. Besides providing with the determination of the critical aspect ratio below which the most unstable perturbations switch from \( m = 0 \) to \( m = 1 \) depending on the Reynolds number, the study shows that perturbations can undergo a rapid transient growth. It is found that helical perturbations always experience the highest transient growth, although for large values of aspect ratio, this transient domination can be overcome by the eventual emergence of axisymmetric perturbation when more exponentially unstable. Furthermore, the adjoint mode, which excites optimally the most unstable mode of the flow, is found to coincide with the optimal perturbation even for short time horizons, and to drive the transient dynamics for finite times. Therefore, the adjoint-based analysis is found to characterize adequately the transient dynamics of jets, showing that a mechanism equivalent to the Orr one takes place for moderate to small wavelengths. However, in the long wavelength limit, a specific mechanism is found to shift the jet as a whole in a way that resembles the classical lift-up effect active in wall shear flows.

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