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Lyapunov exponents, covariant vectors and shadowing sensitivity analysis of 3D wakes: from laminar to chaotic regimes QIQI WANG, MIT, GEORGIOS RIGAS, Caltech, LUCAS ESCLAPEZ, LUCA MAGRI, Stanford, PATRICK BLONIGAN, NASA — Bluff body flows are of fundamental importance to many engineering applications involving massive flow separation and in particular the transport industry. Coherent flow structures emanating in the wake of three-dimensional bluff bodies, such as cars, trucks and lorries, are directly linked to increased aerodynamic drag, noise and structural fatigue.?For low Reynolds laminar and transitional regimes, hydrodynamic stability theory has aided the understanding and prediction of the unstable dynamics. In the same framework, sensitivity analysis provides the means for efficient and optimal control, provided the unstable modes can be accurately predicted. ?However, these methodologies are limited to laminar regimes where only a few unstable modes manifest. Here we extend the stability analysis to low-dimensional chaotic regimes by computing the Lyapunov covariant vectors and their associated Lyapunov exponents. We compare them to eigenvectors and eigenvalues computed in traditional hydrodynamic stability analysis. Computing Lyapunov covariant vectors and Lyapunov exponents also enables the extension of sensitivity analysis to chaotic flows via the shadowing method. We compare the computed shadowing sensitivities to traditional sensitivity analysis. These Lyapunov based methodologies do not rely on mean flow assumptions, and are mathematically rigorous for calculating sensitivities of fully unsteady flow simulations.

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