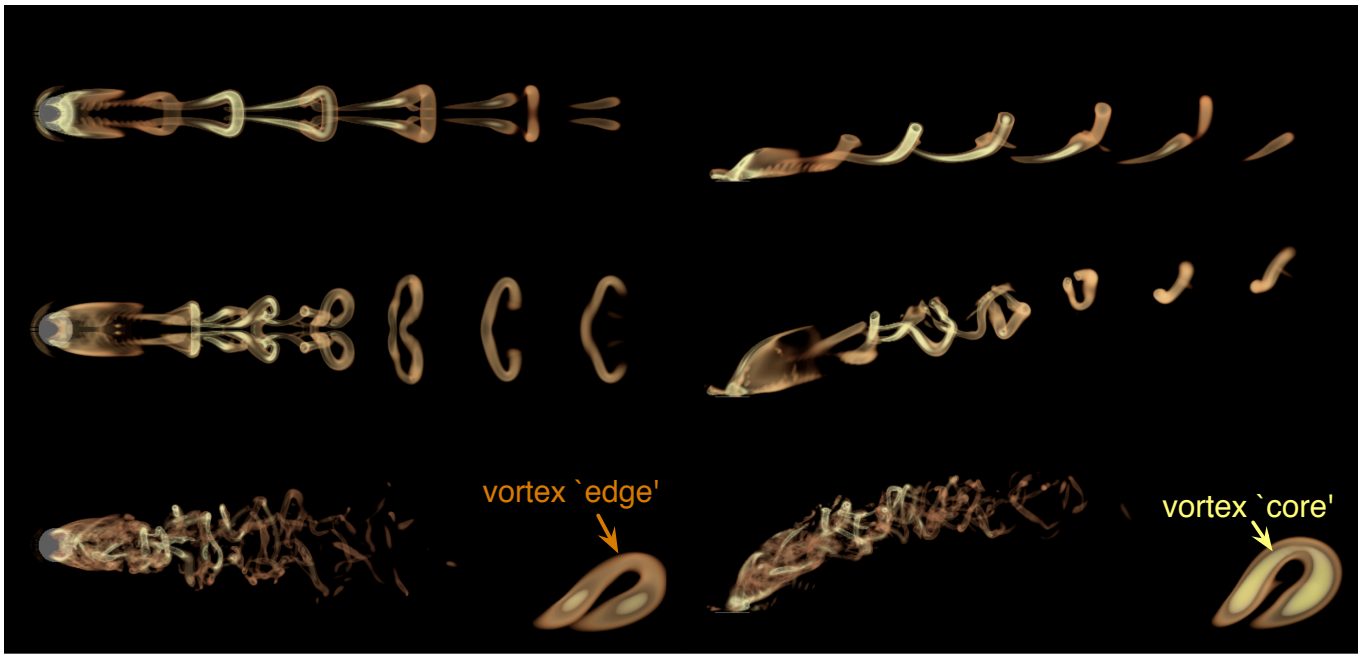


FIG. 1. Views from above (left) and side (right) of the limit cycle for $R = 1$, $R = 2$ and $R = 3$ (top to bottom), showing volume rendering of the $\lambda_2$ vortex identification criterion[1].

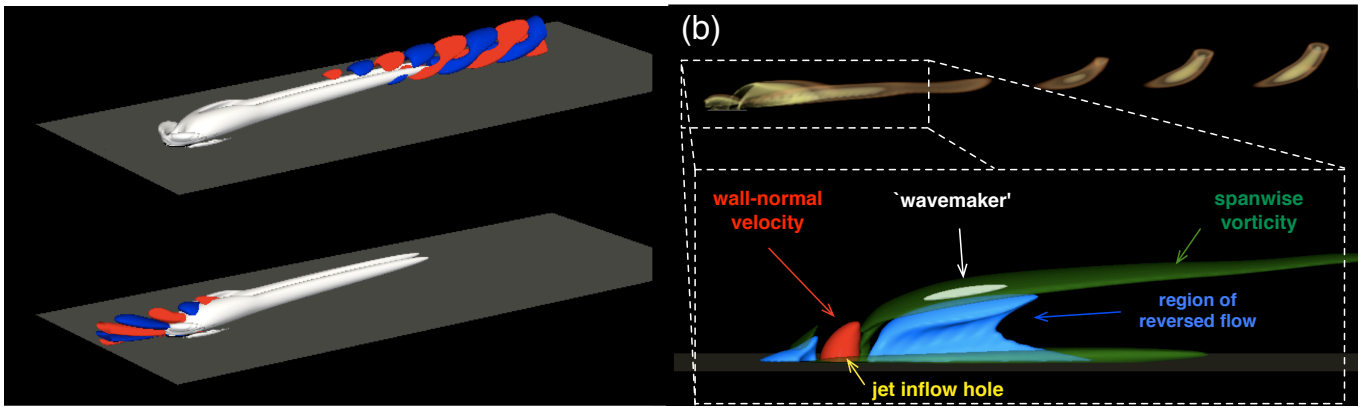


FIG. 2. The unstable global eigenmode and its corresponding adjoint mode (a) and the 'wavemaker' (b) at $R = 0.7$.

# Stability of a jet in crossflow

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We study direct numerical simulations (DNS) of a jet in crossflow at low values of the jet-to-crossflow velocity ratio $R$. As $R$ is increased, the flow evolves from simple periodic vortex shedding (a limit cycle) to more complicated quasi-periodic behavior, before finally becoming turbulent (Fig. 1), as seen in previous simulations[2,3], and in the included video. The first bifurcation is found to occur at $R \approx 0.7$, and the observed shedding of hairpin vortices is possibly linked to a possible existence of a local absolute instability of the shear layer immediately downstream of the jet. We focus on this first bifurcation, and find that a global linear stability analysis predicts exactly the frequency and initial growth rate of the nonlinear DNS simulation at $R = 0.7$. In addition, we compute the adjoint global eigenmodes, and find that the overlap of the most unstable and the corresponding adjoint eigenmode, also known as a 'wavemaker' (Fig. 2), provides additional evidence that the source of the first instability indeed lies in the shear layer above the reversed flow region downstream of the orifice.

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