Predicting Phase Relationships Between VLSM Velocities and Reynolds Stresses via Resolvent Modes

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A resolvent-based model was developed to predict the phase-difference profile between velocity and stress coherent motions measured in a high Reynolds number channel flow as a proxy for predicting large- and small-scale turbulent interactions. The resolvent framework is an input-output model based on the linearized Navier Stokes operator whose mode shapes have been shown to capture key features of turbulent, wall-bounded flows[1]. Recently, an analytical resolvent model for scale interactions was used to identify the sign of the phase difference between large-scale velocity and stress signals at the location of the VLSM peak, consistent with cross-correlation analysis[2]. However, this analytical model was not able to capture the full profile of phase difference across the near-wall region more generally. In this computational study, we developed a new weighting scheme for the resolvent modes to allow for accurate prediction of scale interactions.

A quasi-empirical weighting scheme was used to construct composite large- and small-scale mode shapes from the underlying resolvent modes calculated at different wall-normal locations. The weighting scheme was derived from the observed similarity between the low-rankness measure of the resolvent operator and the streamwise, spectral energy density of wall-bounded turbulence. Figure 1 illustrates the composite VLSM mode shapes for velocity and stress signals and the profile of the phase difference between them, which is shown to be a proxy for the phase-difference between large-scale motions and the envelope of small-scale fluctuations. The ability to predict the phase relationship between large-scale coherent motions and their associated small-scale fluctuations allows for refining and extending resolvent-based models of turbulence to describe small scale features of wall-bounded flows.

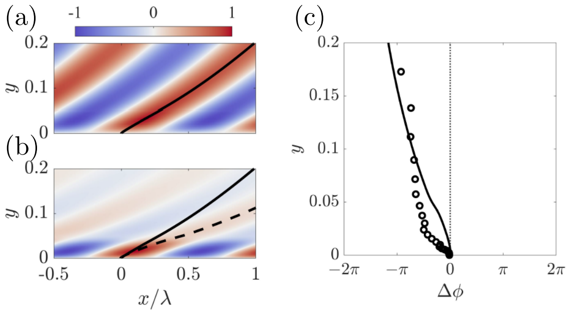

Figure 1: (a) Predicted VLSM velocity modes from the resolvent analysis; (b) the corresponding Reynolds stress mode; (c) The phase difference profile between the modes predicted by the resolvent (solid line) and from a DNS channel flow at $\mathrm{Re}_\tau = 5200$ (circles).

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[1] Taira, *et. al.*, *AIAA J.* **12**, 55 (2017)
[2] Jacobi, *et. al.*, *J. Fluid Mech.* **914**, 1–27 (2021)