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## PERTURBED EDDY-VISCOSITY APPROACH IN RESOLVENT ANALYSIS OF A TURBULENT BOUNDARY LAYER

P. Penet<sup>1,2</sup>, O. Marquet<sup>2</sup>, L. Lesshafft<sup>1</sup>

<sup>1</sup>LadHyX, CNRS, École polytechnique, IPParis, F-91120 Palaiseau, France

<sup>2</sup>DAAA, ONERA, Université Paris Saclay, F-92190 Meudon, France  
pierre.penet@polytechnique.edu

Linear resolvent analysis has proven to be a successful approach for the identification of coherent structures in shear flows. Recent studies of turbulent wall-bounded flows have shown the importance of including the mean eddy viscosity  $\bar{\nu}_T$  in the resolvent operator. In many cases the addition of eddy viscosity allowed to model empirically obtained SPOD modes more accurately, balancing the high non-normality of the resolvent operator [1].

Eddy viscosity depends on the flow variables, and if its inclusion in the linear model is pertinent, it would be consistent to account also for its unsteady fluctuations. We investigate the effect of including a perturbed eddy viscosity  $\nu'_T$  in the resolvent analysis of turbulent boundary layers. A similar model coupled to data-assimilation has yielded promising results in the linear stability analysis of the flow around an airfoil [2]. We consider a spatially developing turbulent boundary layer flow and derive the mean-flow field  $(\bar{u}, \bar{p}, \bar{\nu}_T)$  using the RANS equations closed with the Spalart-Allmaras turbulence model. Analogous to the velocity and pressure fields, we denote  $\nu_T = \bar{\nu}_T + \nu'_T$  to account for an unsteady eddy viscosity perturbation. Linearizing the RANS equations and the Spalart-Allmaras transport equation around the mean-flow solution, we obtain a "perturbed eddy viscosity"  $\nu'_T$ -resolvent in addition to the simple  $\nu$ -resolvent and "frozen eddy viscosity"  $\bar{\nu}_T$ -resolvent.

The  $\nu'_T$ -resolvent correctly identifies the stationary streaks at  $\omega = 0$  as the most energetic structures, for which the spanwise wavenumber dependency is shown in Figure 1. By comparing with the  $\bar{\nu}_T$ -resolvent, we show that accounting for a perturbation in eddy viscosity leads to a reduction in the amplification of streaks. The smaller scale structures developing in the inner layer are more affected and the inner amplification maximum is shifted to smaller wavelengths. The velocity perturbations, seen in Figure 2, also extend further from the wall. Following Symon et al. [3], we will discuss this damping effect from a Reynolds-Orr energy-budget analysis.

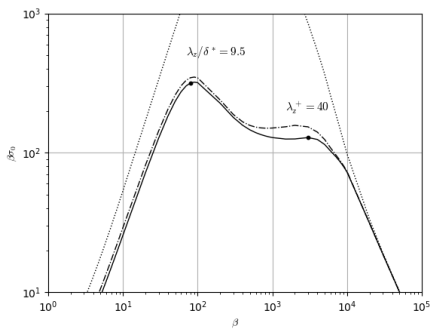


Figure 1: Scaled optimal resolvent gain at  $\omega = 0$  as a function of the spanwise wavenumber  $\beta$ :  $\nu$ -resolvent ( $\cdots$ ),  $\bar{\nu}_T$ -resolvent ( $-\cdot-$ ),  $\nu'_T$ -resolvent ( $-$ ).

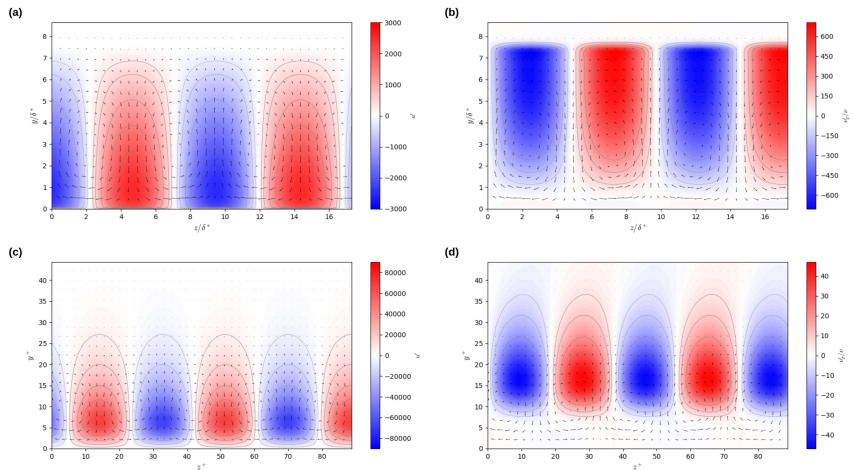


Figure 2: Cross-stream view of the  $\nu'_T$ -resolvent optimal response, colored by streamwise velocity [eddy viscosity perturbation] for outer peak  $\lambda_z/\delta^* = 9.5$  (a) [(b)] and inner peak  $\lambda_z^+ = 40$  (c) [(d)].

### References

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