Modeling energy pathways with nonlinear interactions in transitional flows

Research project

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July 22, 2024

Abstract

Understanding the dominant flow structures that govern the flow physics of transitional boundary layers subject to external forcing is crucial for designing feedback controllers in active flow control applications. In this study, we focus our analysis on the role of linear and nonlinear mechanisms in the resulting flow structures due to external excitation for a wide range of Reynolds numbers. For this task, a structured input-output solver was developed with the aim of studying flow transition characteristics while considering nonlinear interactions. This solver is an extension of our LNS input-output solver that was developed in previous work (Frank-Shapir, 2024). To model the nonlinear effect, we introduce an uncertainty matrix that its feedback-interconnected to the linear transfer function. Two different uncertainty structures were implemented in our study based on studies of Liu and Gayme, 2021, Mushtaq et al., 2023. Three canonical base flows of high importance in transition analysis have been studied: Couette flow, plane Poiseuille flow (PPF), and Blasius flow. For each flow case, we track the variation of several modes of interest that have been identified as dominant for different norms obtained via both linear and nonlinear approaches. We show that streak modes that are predicted via linear input-output analysis lose their dominance when using (nonlinear) structured input-output analysis, where for very low Reynolds numbers, all modes appear to be similar in strength. However, their amplification trends vary with the Reynolds number increase, leading to the interplay between mode dominance for different Reynolds numbers. Our analysis shows that TS mode variation with Reynolds number can be used to accurately identify the critical Reynolds number.

References

Frank-Shapir, O. (2024). Modeling of complex actuation modalities in transitional boundary layers.

Liu, C., & Gayme, D. F. (2021). Structured input–output analysis of transitional wall-bounded flows. *Journal of Fluid Mechanics*, *927*, A25.

Mushtaq, T., Bhattacharjee, D., Seiler, P. J., & Hemati, M. (2023). Structured input-output tools for modal analysis of a transitional channel flow. *AIAA SCITECH 2023 Forum*, 1805.