

Flow-Induced Instabilities and Wake Dynamics of a Reconfigured Plate

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ABSTRACT

Flexible structures subjected to fluid flow experience complex wake dynamics due to the interplay between elastic reconfiguration and flow-induced instabilities. At low to moderate flow speeds, flexibility enables drag reduction by allowing the structure to adapt to the flow. However at higher speeds, dynamic instabilities emerge leading to unsteady wake patterns and fluctuating loads. Understanding these mechanisms is key to predict the aerodynamic behavior of flexible systems.

In this study, we analyze the wake of a thin, flexible plate clamped at its midpoint and placed normal to an airflow, serving as an idealized model of reconfigurable natural structures like trees subjected to wind or seagrass subjected to water flow. To capture the flow dynamics, we conduct an experimental wind tunnel campaign using Particle Image Velocimetry (PIV). Since our PIV data is non-time-resolved, we apply a decomposition-based methodology—combining Proper Orthogonal Decomposition (POD), Robust Principal Component Analysis (RPCA), and Singular Value Decomposition (SVD)—to reconstruct the flow. This allows us to extract dominant flow patterns and infer the evolution of coherent structures. We identify multiple wake modes, some of which correlate with symmetric and anti-symmetric oscillations of the plate.

To recover time-dependent behavior, we use Dynamic Mode Decomposition (DMD) on double-pulse laser images, identifying key frequency components of the system. This approach provides insight into whether vortex shedding frequencies emerge and how they interact with structural flexibility. By analyzing the spatial and temporal characteristics of the wake, we distinguish between different instability mechanisms such as vortex-induced vibrations (VIV) and flutter.

This study also examines the impact of the plate's aspect ratio on the wake three-dimensionality. As the aspect ratio increases, three-dimensional effects in the wake are attenuated, and the dynamic behavior of the plate becomes more aligned with the vortex shedding frequency. Higher aspect ratios cause the plate to respond more uniformly to the shedding vortices, leading to vibrations at a frequency close to the vortex shedding frequency. This insight sheds light on the role of structural geometry in fluid-structure interactions.