# Dynamics of a flapping plate in laminar and turbulent flows

B. Nagy*[†], S. Olivieri[‡], R. Verzicco *[§][¶], F. Viola *

Self-sustained, flow-induced oscillations of a flexible plate has been identified as a viable mechanism for energy harvesting [1]. However, the efficiency of such energy-harvesting devices strongly depends on the onset of aeroelastic instabilities[1]. Restricting ourselves to inextensible plates, these instabilities depend on four key non-dimensional parameters: the Reynolds number, the structure-to-fluid mass ratio, the bending rigidity, and the aspect ratio of the plate.

In this talk, we address recent advances in the numerical and theoretical modeling of three-dimensional flow around a flapping plate subjected to viscous laminar and turbulent inflow conditions.
To this aim, our *in-house* numerical code [2] is used to solve the fluid-structure interaction problem.
The parametric space is explored and the onset of the fluid-structure instability is predicted by extending the theory of Connel and Yue [3] to account for the finite span of the plate through a modified added mass coefficient.
Specifically, three distinct regimes of response can be identified in the parametric space [3]: (i) fixed-point stability, (ii) limit-cycle flapping, and (iii) chaotic flapping. We present a comprehensive mapping of the flapping modes in the $M - K_B$ plane, covering an extensive region of the parametric space (see Figure 1).

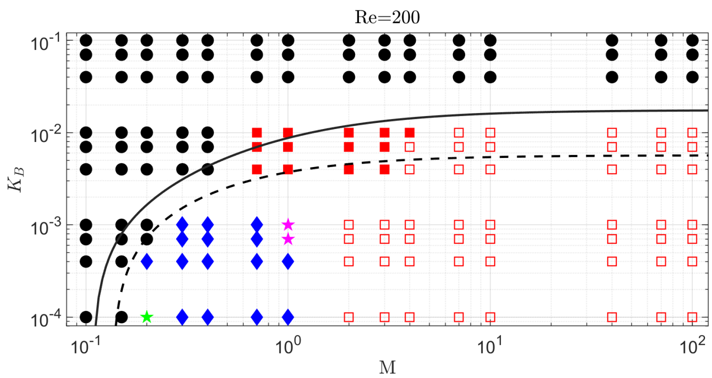


Figure 1: Overview of the typical deformation state regions on the $M$-$K_B$ plane for $Re = 200$, where the symbols •, ■, ★,♦, and ★ represent the straight, mode 2, mode $2+3$, mode 3, and mode 4 flapping modes, respectively. Empty markers indicate irregular flapping.
The dashed (╌╌╌ ) and solid (——) lines denote the original and modified model of Connel and Yue [3].

For each case, we investigate the flapping dynamics (including peak-to-peak amplitude and Strouhal number) and assess the energy-harvesting performance of the plate by measuring the elastic strain energy and calculating the energy conversion ratio [1]. Consequently, the optimal flow configurations for energy harvesting are identified in all flow regimes and rationalized by monitoring the effect of bending rigidity and mass ratio on the corresponding flapping dynamics.
The most important cases for energy harvesting are then revisited under turbulent inflow conditions. Turbulence is promoted by placing a passive grid at the inlet of the computational domain [4]

*Gran Sasso Science Institute (GSSI), Viale F. Crispi 7, 67100, L'Aquila, Italy
[†]INFN-Laboratori Nazionali del Gran Sasso, Via G. Acitelli 22, 67100 Assergi (AQ), Italy
[‡]Università degli Studi di Genova, Department of Civil, Chemical and Environmental Engineering, Via Montallegro 1 - 16145 Genova (GE), Italy
[§]Department of Industrial Engineering, University of Rome Tor Vergata, Via del Politecnico 1, 00133, Rome, Italy
[¶]Physics of Fluids Group, University of Twente, Faculty of Science and Technology, 7500AE Enschede, The Netherlands
[1]Michelin and Doaré, *Journal of Fluid Mechanics* **714** (2013).
[2]Viola et al., *Computer physics communications* **273** (2022).
[3]Connell and Yue, *Journal of Fluid Mechanics* **581** (2007).
[4]Olivieri et al., *Physics of Fluids* **33 (8)** (2021).