Wake instabilities and trajectories of porous bluff bodies

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The flow of a liquid phase through a body containing interconnected voids is frequently encountered in engineering applications as well as in nature. From insect flight to seed dispersion, studying the interaction between porous structures and the surrounding flow helps us understand optimization strategies employed by nature during evolution and informs the design of engineering processes, such as the dispersion of small sensors for environmental sensing.

Inspired by these concepts, I will present the wake and path instabilities that arise around various porous bluff bodies at low Reynolds numbers. Through a combination of numerical simulations, hydrodynamic instability theory, and desktop-scale experiments, I will show recurrent flow patterns that govern these systems depending on the permeability of the body. In fact, these flows may or may not exhibit periodic vortex shedding in their wake, with a critical permeability threshold beyond which the instability is suppressed. I demonstrate that these results can be generalized to any solid structure exhibiting the same permeability, regardless of pore shape.

Building on these findings, I develop efficient optimization procedures based on macroscopic, measurable flow objectives and extend them to higher Reynolds numbers as well as to cases involving osmosis. Subsequently, I analyze the settling of porous objects, specifically, one case characterized by microscopic permeability, such as the pappus of dandelion seeds, and another characterized by macroscopic permeability, like an annular disk. I show how permeability modifies trajectories and conclude by demonstrating the relevance of these findings for the dispersion of small sensors in environmental sensing applications.

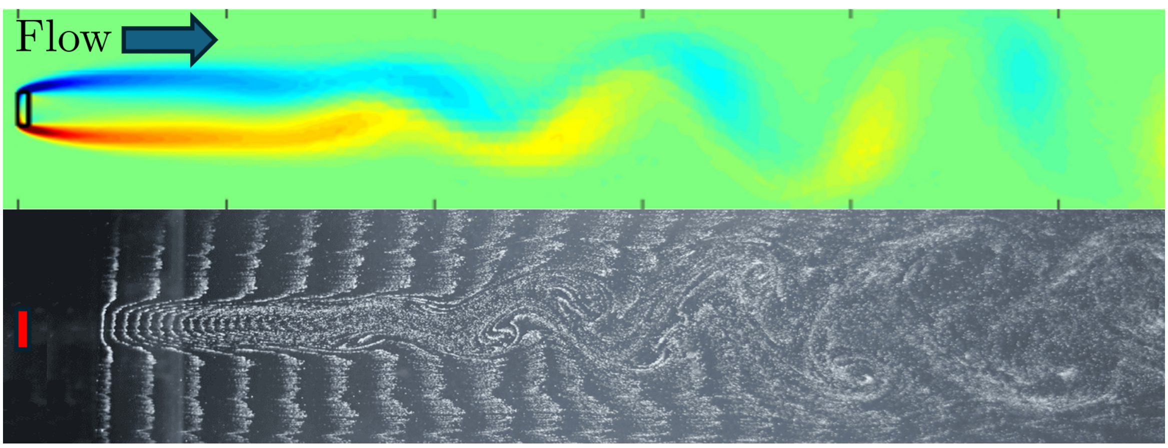

Figure 1: *The 2D flow around a highly permeable rectangle: numerics (on the top) and visualization with hydrogen bubbles (on the bottom) of the wake. Downstream of the object, a steady shear layer develops and destabilizes at a large distance from the body, with the formation of a von Karman vortex street.*