INTERNSHIP/PHD

TUNABLE DYNAMIC BEHAVIOR OF KIRIGAMI IN FLUID FLOW

Supervisors: Sophie Ramananarivo, sophie.ramananarivo@polytechnique.edu
Start date: anytime from Jan. 2025
Host laboratory: LadHyX, Ecole Polytechnique

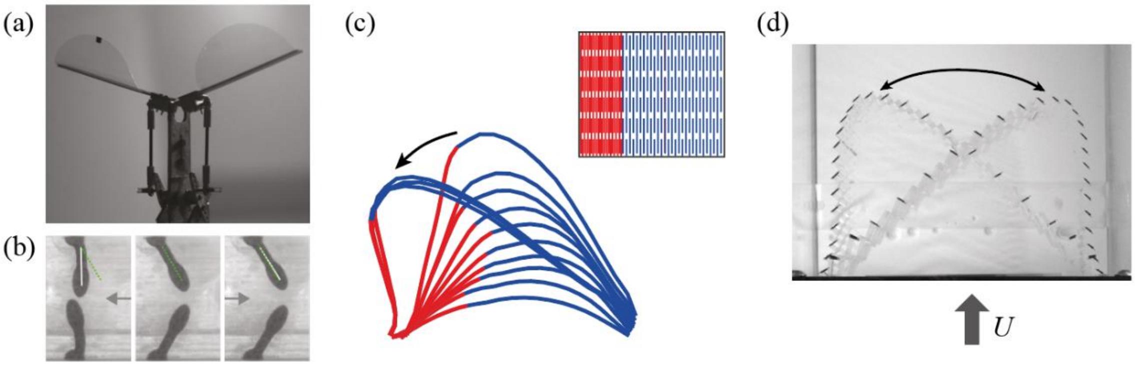

Figure 1: (a) The flexible wings of a robotic insect enhance its propulsion [1]. (b) Soft valve that autonomously open or close depending on the direction of the flow [2]. (c) Composite kirigami, featuring regions of varying stiffness (in blue and red), which undergoes a sudden shape transition as flow speed increases. (d) Flow-induced oscillations above a critical flow velocity U.

Context: In engineering, flexible components are increasingly favored over rigid ones for devices operating in fluid flow, as their ability to deform enhances resilience and adaptability to changing conditions. These shape-shifting properties can also improve aerodynamic performance (Fig.1a) and serve functional roles, such as acting as valves (Fig.1b), without external actuation. However, soft components are harder to control than rigid ones, requiring a better understanding of how they passively deform under fluid forces and strategies to program their behavior. A promising approach is using kirigami, inspired by the Japanese art of paper cutting, to program deformation in response to flow, as shown by research at LadHyX [3].

While our primary focus has been on static and quasi-static behaviors, understanding the dynamic fluid-elastic response is also crucial. Slender structures in transverse or axial flow are prone to self-induced oscillations and buckling [4]. These fluid-elastic instabilities can enable dynamic functionalities, such as harvesting energy from marine currents through oscillatory motion. Additionally, rapid geometric changes can minimize excessive loads by shifting to drag-reducing shapes or acting as velocity threshold sensors. Both phenomena have been observed in experiments at LadHyX (see Fig.1c-d). Conversely, some structures must resist instability to maintain structural integrity, highlighting the need to evaluate the stability of deformed configurations for reliable design.

Goals: The objective of the internship is to investigate static and dynamic flow-induced instabilities in such porous and elastic structures. We will experimentally characterize the mechanical response of kirigami sheets to flows (and conduct flow visualizations), as a function of the cutting pattern and fluid velocity. This experimental study will be combined with theoretical modelling and stability analysis to better understand the fluid-structure mechanisms underlying these instabilities.

Profile: Candidates should have a good training in Fluid mechanics, Soft Matter or Continuum mechanics. A strong taste for both experiments and theoretical analysis is a plus. *PhD opportunity after the internship.*

[1] S. Ramananarivo, R. Godoy-Diana and B. Thiria, “ Rather than resonance, flapping wing flyers may play on aerodynamics to improve performance,” PNAS, vol. 108, no. 15, p. 5964–5969, 2011.
[2] Brandenbourger, M., Dangremont, A., Sprik, R., & Coulais, C. (2020). Tunable flow asymmetry and flow rectification with bio-inspired soft leaflets. Phys. Rev. Fluids, 5(8), 084102.
[3] Marzin, T., Le Hay, K., de Langre, E., Ramananarivo, S., 2022. Flow-induced deformation of kirigami sheets. Phys. Rev. Fluids 7, 023906.
[4] M. P. Paidoussis, Fluid-structure interactions: slender structures and axial flow, Academic press, 1998.