M2 INTERNSHIP:

Embracing fluid-structure interactions to achieve new functionalities

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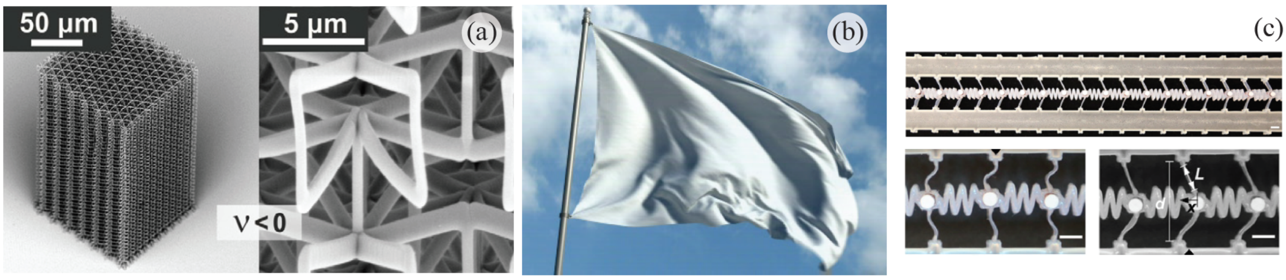

Figure 1: (a) Mechanical metamaterial which expands in the transverse direction (instead of compressing) when stretched vertically [1]. (b) Common outcome of fluid/structure coupling: flag fluttering in the wind. (c) Mechanical waveguide that unidirectionally propagates pulses over long distances without any signal degradation waveguide [3].

This project is rooted in the expanding context of architected materials, like the one shown in Fig 1a. Those metamaterials are characterized by a microstructure that is specially designed to achieve unique bulk properties [2], such as the mechanical ability to expand in the transverse direction when stretched (see Fig 1a). The morphology of the solid structure dictates its mechanical properties, but we can also make use of a fluid phase. Such is the case, for instance, of plants that contain fluid-filled channels which allow them to modify their stiffness through changes in internal hydrostatic pressure. A plant thus bends or rigidifies depending on water availability, following instructions embedded in its own architecture.

While plants make use of an internal fluid, another option that will be explored in this internship is to rather exploit the external fluid surrounding the structure. Objects interacting with wind or water flows exhibits fascinating behaviors; to convince yourself you can look at a flag fluttering in strong winds due to aero-elastic instabilities (Fig 1b). Such immersed object is subjected to motion-dependent fluid forces that act as an added mass or added stiffness or damping that significantly modify its dynamic. For instance, it modifies the way it responds to a forcing and mechanically propagates a signal. By carefully architecting the structure, we can exploit such effects to tailor fluid-dependent mechanical behaviors. In particular, it paves the way for new generations of mechanical waveguides in the spirit of that of Fig 1c [3].

In this internship, we will build and study the properties of waveguides consisting of a periodic lattice of masses connected by elastic links, and immersed in a fluid. The aim is to understand how fluid/structure interaction at the scale of a unit cell dictates the global properties of the structure. It has potential for achieving waveguides that transmit signals in a designated direction but not others, and more generally for engineering the wave response. This experimental study will be coupled to theoretical modeling to understand how specific geometries allow for tailored functionalities.

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[1] Bückmann T. et al (2012). Tailored 3D mechanical metamaterials made by dip-in direct-laser-writing optical lithography. *Advanced Materials*, 24(20), 2710-2714.

[2] Bertoldi, K., Vitelli, V., Christensen, J., & van Hecke, M. (2017). Flexible mechanical metamaterials. *Nature Reviews Materials*, 2(11), 17066.

[3] Raney, J. R., Nadkarni, N., Daraio, C., Kochmann, D. M., Lewis, J. A., & Bertoldi, K. (2016). Stable propagation of mechanical signals in soft media using stored elastic energy. *Proceedings of the National Academy of Sciences*, 113(35), 9722-9727.