Modeling and simulation of periodic inflatable materials

Master-level internship (research), could be extended to a PhD

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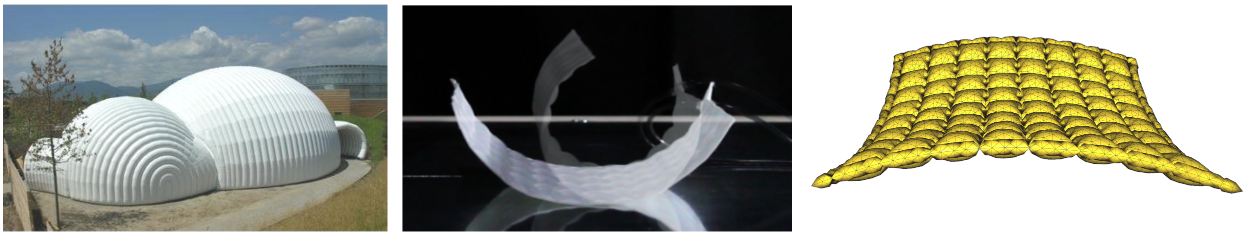

Figure 1: Left: Inflatable architectural structure (fstructure.com). Middle: heat-sealed fabric changing its shape upon inflation [1]. Right: simulation of a periodic inflatable material.

Context

Inflatable structures have many applications in multiple fields such as architecture, entertainment, robotics and more. They can be used for temporary shelters (Fig.1, left), soft robots, packaging, floating devices (buoys, pneumatic canoes), furniture (inflatable mattresses) to give a few examples. In practice, most of these structures are made of tubular chambers, which are easy to fabricate and whose mechanical behavior is well understood. However, the high anisotropy in the tubular pattern translates to mechanical anisotropy and limits the space of shapes that can be reproduced. More specifically, since tubes easily bend in one direction only, the structure generally assumes a piecewise developable shape once inflated.

Our goal is to expand the capabilities of inflatables by leveraging a richer set of periodic parametric patterns, such as the ones shown in Figure 1 (middle, right). Indeed, by tiling theses patterns and adequately choosing their parameters we should be able to locally modulate the mechanical properties of the structure and therefore to control its final shape.

Objectives

The inflatables that we consider are made of two planar membranes which are sealed according to a given pattern regularly repeated to form a periodic padding. As a first step, we want to study the mechanical behavior of the resulting periodic inflated chambers as a function of the pattern parameters (e.g. shape of the pattern curves). To do so, we will rely on homogenization methods [2] that will allow us to precisely model the behavior of the inflatable thanks to an efficient and systematic study of the membrane and bending stiffnesses of the equilavent homogenenous plate. To compute the shape of the inflatables, we will use a C++ simulator tailored to the simulation of such structures [3]. This simulator relies on a finite element method and a convexified membrane model that can robustly handle the large deformations and buckling of the membrane. As part of the work, this simulator will need to be extended to support periodic structures, and appropriate boundary conditions (and their handling) will need to be implemented.

This internship will give you the opportunity to learn about multi-scale modeling, non linear mechanics for large deformations, structural modeling and numerical methods for simulation.

If successful, this master's thesis is expected to lead to a PhD thesis on the inverse design of free-from structures made of inflatable periodic chambers.

Work environment and requirements

This internship will take place at Inria Grenoble – Rhône-Alpes and will be supervised by Mélina Skouras (melina.skouras@inria.fr) and Arthur Lebée (arthur.lebee@enpc.fr).

The candidate should have strong programming and mathematical skills, and ideally knowledge in continuum mechanics and numerical simulation.

References

[1] J. Ou, M. Skouras, N. Vlavianos, F. Heibeck, C.-Y. Cheng, J. Peters, and H. Ishii. Aeromorph - heat-sealing inflatable shape-change materials for interaction design. ACM UIST, 2016.

[2] Karam Sab and Arthur Lebée. *Homogenization of Thick and Heterogeneous Plates*. Wiley, 2015.

[3] Mélina Skouras, Bernhard Thomaszewski, Peter Kaufmann, Akash Garg, Bernd Bickel, Eitan Grinspun, and Markus Gross. Designing inflatable structures. *ACM Trans. on Graphics*, 33(4), 2014.