36th INTERNATIONAL CAE CONFERENCE AND EXHIBITION
Virtual Event - 2020, November 30 – December 4

Computer-assisted design defines a novel actuation principle based on *liquid structures*

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Abstract

We present a framework for new structural metamaterials we refer to as *liquid structures*: a topology of bistable mechanisms made up of a high number of cells that are sub-mechanisms composed of pseudo-rigid links and joints. The name liquid structures comes from the similarities they present with the kinematics of the constant flow of incompressible fluids they are inspired to in a limited domain. Computational Fluid Dynamics (CFD) is employed to define the layout of the cells through a two-step process where: (i) the node displacements are computed by the CFD tool itself; (ii) the kinematic synthesis of each cell is subsequently performed. We report an illustrative case and an example of application (a brake system) where star- and diamond-type cells are employed. Our proposal opens a new avenue of computer-assisted design of mechanical actuators.

Liquid structures from CFD simulations

The goal of the research is to propose a new concept for the mechanical transmission within a structural system for actuation. It combines techniques used in **mechanisms synthesis** (linkage synthesis) with **Computational Fluid Dynamics** (CFD). These tools allow to create soft modes that spread along narrow and connected 'channels' to kinematically link one boundary location of the structure (e.g. face A in Fig. 1a) to a far away one (e.g. face B in the same figure). The transmission is assured by a set of links (revolute and prismatic) and joints that are designed by **interpreting the output of a CFD simulations**.

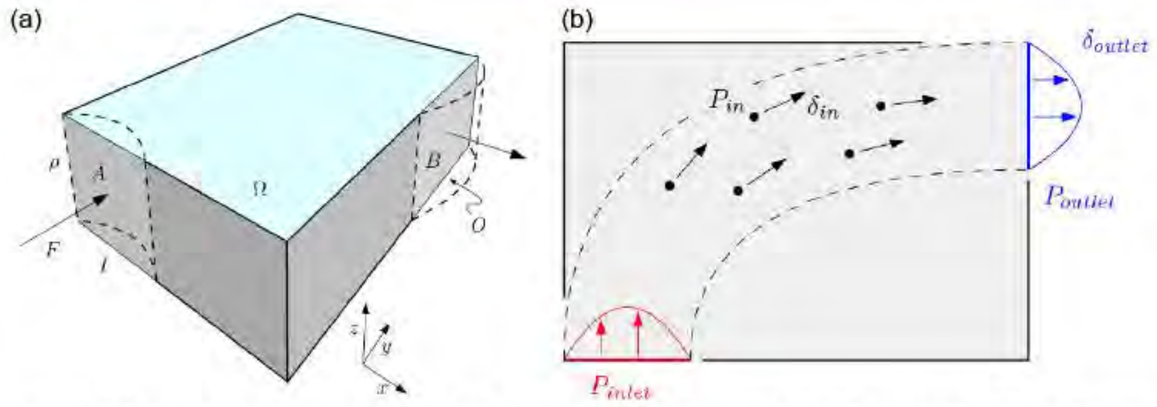

Figure 1: (a) How to mechanically actuate B from an input given in A? (b) By exploiting the outcome of a CFD simulation where inlet (red arrows) corresponds to face A and outlet (blu arrows) to face B; the flow within the domain is interpreted as a mechanical soft mode to be realized by linkages.

The steps to achieve the required liquid structure are the following:
1) INPUT and OUTPUT displacements of the mechanism correspond to the INLET and OUTLET velocities for the CFD calculations performed on the same domain (Fig. 1b);
2) the liquid structure is subdivided into cells (MESH M) (Fig. 2a) each of them containing a linkage with at least 4 DOFs (Fig. 2b);
3) the CFD simulation is performed with a computational mesh (MESH C) that is constructed on MESH M;
4) by exploiting the analogy, the velocities obtained of nodes belonging to MESH M by CFD (Fig. 2c) corresponds of the displacements of each cell;
5) the displacements allow the mechanical synthesis of each cell so that the configuration of each linkage can be defined; Fig. 2d shows, in black, the actuated configuration.

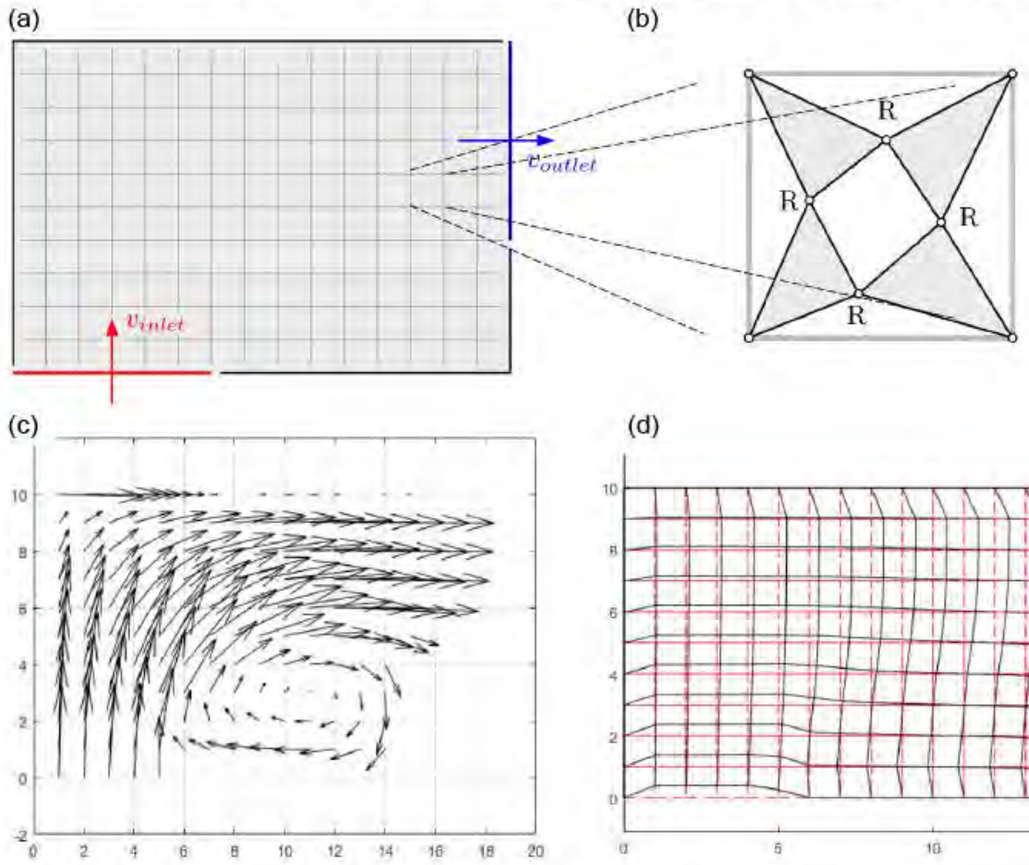

Figure 2: Prototype example of the design of a liquid structure: (a) mesh of the mechanical system: each of the 150 cells contains a 4-DOFs linkage to be designed. (b) Example of linkage (star cell). (c) Velocity field obtained from the CFD simulation. (d) Actuated configuration (in black).

Star and diamond cells

For the 4-DOFs linkage in each cell, we propose the use of two possible types of linkages: star cell (Fig. 3a) and diamond cell (Fig. 3b). The positions of the inner nodes in each cell depend on the mechanical synthesis performed after the CFD simulation.

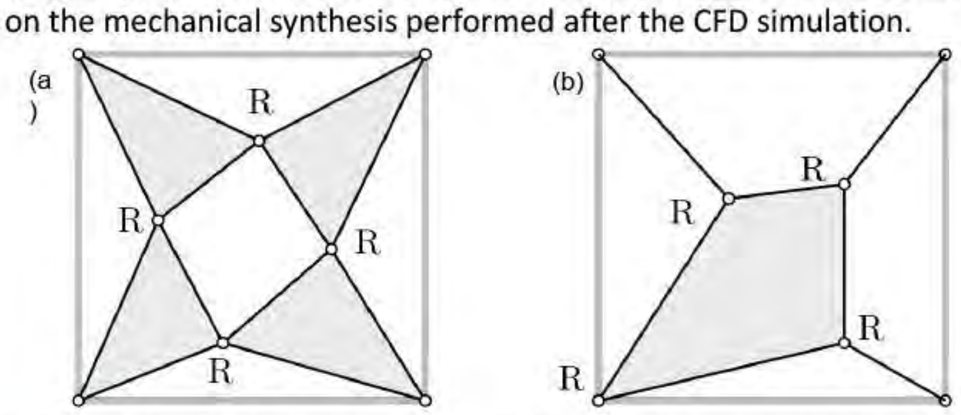

Figure 3: (a) Example of star cell. (b) Example of diamond cell. R indicates a revolute joint.

A brake system as a liquid structure

As an example, we propose the use of the liquid structure paradigm in the design of a brake system. Usually the pads are squeezed against the disc through hydraulic actuation. A liquid structure can produce an equivalent squeezing action without the need of pistons and cylinders. This solution is innovative because the actuation system is integrated within the caliper structure and it is possible, in this way, to reduce remarkably the number of mechanical components.

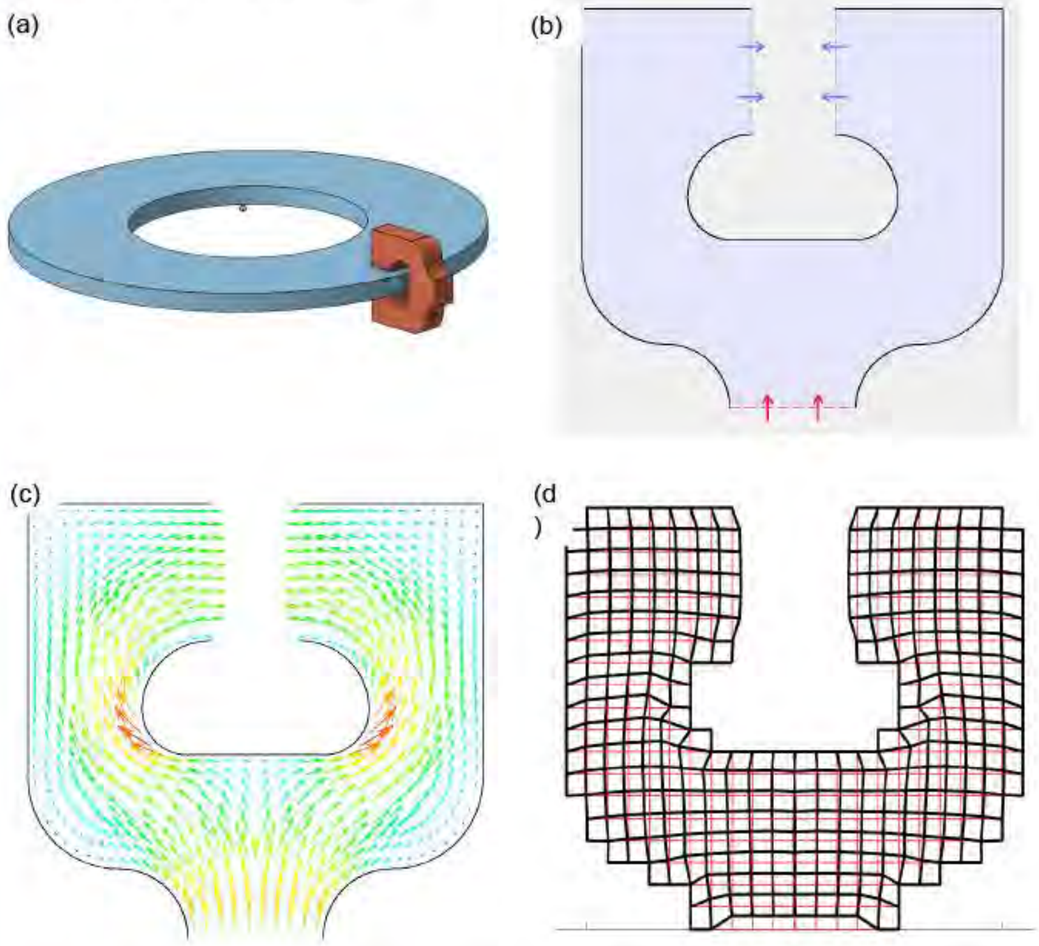

Figure 4: (a) Sketch of the brake system. (b) Domain of the CFD simulation with inlet (red arrows) and outlet (blue arrows) zones. (c) Velocity profile computed by CFD software. (d) Sketch of the arrangement of mechanism cells to ensure mechanical transmission and the designed braking performance.

Conclusions

We show how the use of Computational Fluid Dynamics simulation tools may lead to the design of novel metastructures, called liquid structures, paving the way to a new avenue in the design of Computer Assisted mechanical actuation. A brake system illustrates the application of our proposal.

Acknowledgement

This work has been partially supported by the PRIN project "SEDUCE" n. 2017TWRCNB.

Reference

P. Gallina, M. Gei, L. Scalera, S. Seriani (2020) Liquid structures: a novel Computational Fluid Dynamics (CFD) inspired metamaterial. Submitted.