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DATA-DRIVEN KINEMATICS-CONSISTENT MODEL ORDER REDUCTION OF FLUID-STRUCTURE INTERACTION PROBLEMS: APPLICATION TO MICROCAPSULES IN FLOW.

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Today the solution of fluid-structure interaction (FSI) problems is central to numerous engineering and bioengineering applications. High-fidelity numerical simulations are developed for computed-aided analysis. However, they are very time-consuming even when using high-performance computing facilities. To reduce the computational cost, model-order reduction methodologies have been developed. Efficient intrusive reduced order models (ROM) for FSI have been proposed e.g. in [1]. But there are far less contributions in non-intrusive ROMs dedicated to FSI.

We propose a generic approach of a dynamical data-driven model-order reduction technique for three-dimensional FSI problems. We use a coupling between Proper Orthogonal Decomposition (POD) and Dynamic Mode Decomposition (DMD), and a Tikhonov regularization for robust identification purposes. The method is designed to be non-intrusive: the results of the three-dimensional capsule dynamics simulated by a high-fidelity solver (called also Full Order Model (FOM)) [3, 4] are used as input of the ROM. The ROM methodology is thus data-driven. The ROM is consistent with the equations of kinematics: the model returns the displacement and velocity fields from a few snapshots provided by the FOM. To show the potential of the method and identify its limits, we will apply it to canonical examples of a microcapsule (liquid droplet enclosed by a thin hyperelastic membrane) subjected to an external flow (microchannel or simple shear flow) [2].

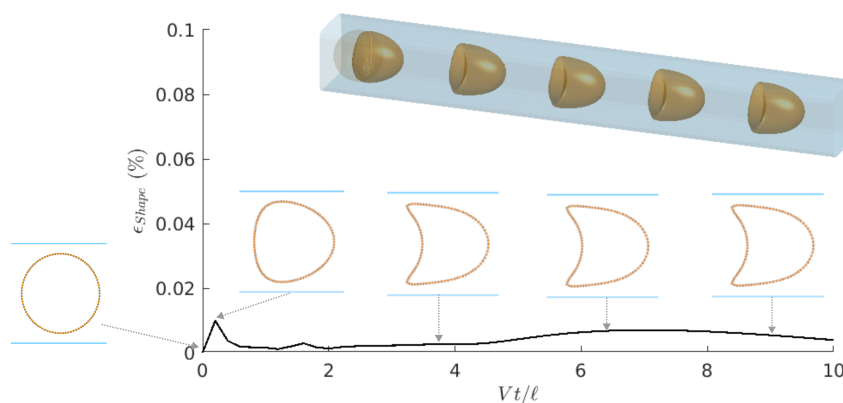


Figure 1. Temporal evolution of the difference between the 3D reference capsule shape given by the FOM and the 3D shape predicted by the ROM ($Ca = 0.13$, $a/l = 0.8$). The inserts shows the 3D dynamics predicted by the ROM and the comparison of the capsule shapes in the channel mid-plane (black: FOM, orange: ROM).

In the case of a capsule flowing in a microchannel with a square section, the FOM is used to get a complete numerical training database of the capsule dynamics as a function of the parameters of the problem:

- The capillary number Ca , which measures the ratio between the viscous forces acting onto the capsule membrane and the membrane elastic forces,

- The capsule-to-tube confinement ratio a/ℓ , when the external flow is confined.

An interpolation method is implemented to predict the solution for any values of governing parameters that are not part of the training database. We get very satisfactory results. The model is able to predict the capsule dynamics for any $(a/\ell, Ca)$ couple. The temporal evolution of the difference between the 3D capsule shape predicted by the ROM and that given by the FOM is illustrated in Fig. 1 for a channel flow. The maximum difference is 0.01% in this case and never exceeds 0.3% over the entire range of parameter values. The excellent agreement is proven by the inserts showing the superposition of the two profiles in the mid-plane. Comparing the computational times, we obtain a speedup of the online stage varying between 4200 when $Ca \geq 0.05$ and 52106 for the lowest tested value of Ca . It is thus possible to estimate the capsule dynamics very precisely with the developed ROM, while considerably reducing the computational time.

References

- [1] Quarteroni A., Manzoni A., Negri F.: Reduced basis methods for partial differential equations - An introduction. Springer International Publishing, 2016.
- [2] Dupont C., De Vuyst F., Salsac A.-V. Data-driven kinematics-consistent model order reduction of fluid-structure interaction problems: application to deformable microcapsules in a Stokes flow. *J. Fluid Mech*, **995**: A2, 2023.
- [3] Walter J., Salsac A.-V., Barthès-Biesel D., Le Tallec P. Coupling of finite element and boundary integral methods for a capsule in a Stokes flow. *IJNME*, **83**: 829–850, 2010.
- [4] Hu X.-Q., Salsac A.-V., Barthès-Biesel D.: Flow of a spherical capsule in a pore with circular or square cross-section. *J. Fluid Mech*, **705**: 176 – 194, 2012.