

Data-driven kinematics-consistent model order reduction of fluid-structure interaction problems: application to microcapsules in flow

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Abstract

Today the resolution 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 robustness purposes. An interpolation method is implemented to predict the solution for any values of governing parameters that are not present in the training database. As application, we will consider the dynamics of a deformable capsule flowing into a microchannel. Microcapsules, which are liquid droplets enclosed by a thin hyperelastic membrane, can be used as innovative drug delivery carriers through blood vessels.

The method has been designed to be non-intrusive: the results of the three-dimensional capsule dynamics simulated by the high-fidelity solver (called also Full Order Model (FOM)) developed by [2] 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. The FOM was used to get a complete numerical database of the capsule dynamics as a function of the parameters of the problem: the capsule-to-tube confinement ratio a/ℓ , and the capillary number Ca , which measures the ratio between the viscous forces acting onto the capsule membrane and the membrane elastic forces. The model is able to predict the capsule dynamics for any $(a/\ell, Ca)$ couple. A maximum error of 0.3% on the capsule shape is measured on all the domain and the speedup varies between 52106 for the lowest value of Ca tested and 4200 when $Ca \geq 0.05$. It is thus possible to estimate the capsule dynamics very precisely with the developed ROM, while considerably reducing the computational time.

References

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