Hierarchical Surrogate Modeling for Droplet-Laden Stokes Flows

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Abstract

We present a surrogate modeling strategy for Stokes flows where deformable liquid droplets are suspended in a carrier fluid [1]. Our approach is based on a multi-fidelity framework: at the lowest fidelity, droplets are treated as passive tracers, neglecting their influence on the ambient flow field. Building on this approximation, we derive a PDE whose solution represents the current modeling error. This error equation is then solved approximately to correct the flow field, and the procedure is iterated.

Two fidelities are employed in an alternating fashion: Stokes flow in the absence of droplets and flow around a single droplet in free space. By systematically combining these models, the method can capture droplet-flow, droplet-boundary, and droplet-droplet interactions. If the droplets are geometrically similar, we further develop an efficient strategy that exploits this structure through an offline–online decomposition, enabling the reuse of precomputed single-droplet solutions. Numerical experiments demonstrate the accuracy and efficiency of the proposed surrogate across a range of tests, including scenarios with up to 10^5 droplets. Notably, we show that the proposed surrogate achieves significantly reduced computational cost compared to fully resolved multi-fluid simulations with state-of-the-art software.

References

[1] D. Pradovera, T. Frachon, and S. Zahedi, "Hierarchical surrogate modeling for droplet-laden Stokes flows", in preparation.