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ADVANCES IN HYPER-REDUCTION-BASED MODEL ORDER REDUCTION FOR COMPUTATIONAL FLUID DYNAMICS

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ABSTRACT

High-fidelity (HF) numerical simulations based on finite volume and finite element methods play a central role in computational fluid dynamics, enabling the accurate modeling of complex flows and multi-physics interactions. However, their computational cost becomes prohibitive in many-query contexts, including optimization, control, and uncertainty quantification. These scenarios are particularly demanding in multi-material and fluid-structure interaction problems, where large deformations, strong coupling, disparity in wave speeds, complex geometries, and material interfaces increase computational and memory cost.

Model Order Reduction (MOR) techniques aim to alleviate this burden by approximating the HF dynamics in low-dimensional spaces. While MORs can significantly reduce the number of degrees of freedom, their efficiency is often limited by the cost of evaluating nonlinear terms, which typically still involves operations at the scale of the HF model. In this context, hyper-reduction techniques become crucial for the practical efficiency of MORs. Instead of performing computations that scale with the full set of degrees of freedom associated with the HF discretization, these methods leverage a small number of strategically selected spatial points to approximate nonlinear operators and inner products, leading to a substantial reduction in computational complexity.

This MS focuses on recent advances in MORs based on hyper-reduction methods for nonlinear systems arising in computational fluid dynamics. The aim is to bring together contributions addressing both methodological developments and challenging applications, with particular attention to accuracy, robustness, and structure preservation. Topics of interest include, but are not limited to: collocation-based and projection-based hyper-reduction; gappy Proper Orthogonal Decomposition (POD) and sampling-based techniques; dynamic selection of POD modes and collocation points; and the integration of hyper-reduction with data-driven and machine learning methods.