Model Reduction for Reacting Flow Applications

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ABSTRACT

Design of future aircraft engines and fuels demands increased fuel efficiency, reduced pollutant emissions, and reduced greenhouse gas production. These improvements require the detailed knowledge of the combustion process. However, despite rapid increase in computational power and hardware capacity, numerical simulation of reacting flows with detailed chemistry remains a challenging and computationally demanding task. Simulation of reacting flows requires the numerical integration of a system of nonlinear partial differential equations coupling conservation laws, equations of state, and equations describing the chemical source terms. Solving these systems is particularly challenging due to the stiffness of the embedded kinetics and the high computational cost of integrating the source term that arises from the chemical models. We present a model reduction approach that addresses these challenges by providing a systematic means to derive reacting flow models that are fast to solve but retain high-fidelity predictive capability.

Existing approaches used to reduce chemical models, such as the computational singular perturbation [1] and the intrinsic low dimensional manifold [2] methods, are based on separation of reaction timescales, and do not always result in sufficient levels of reduction. An alternative approach is to use the proper orthogonal decomposition (POD) [3], which computes a low-order basis from an ensemble of representative solutions, or "snapshots", and then projects the governing equations onto the low-order subspace defined by this basis to obtain the reduced-order model. While the POD has been used widely for model reduction in fluid dynamics, its application to reacting flows presents several challenges. First, the metrics used to distinguish dominant modes must be chosen carefully. In the reacting flow setting, fast reactions may appear unimportant by the standard 2-norm measure of contribution to the ensemble energy; however, their representation in the basis may be essential for accurate results. Second, the snapshots must be selected carefully so that both transient and steady-state reaction behaviors are captured. Third, it may be important to include information regarding the outputs of interest through adjoint or sensitivity information.

In this work, we discuss a specific method of applying POD in the context of reacting flow models. We present an application to an example combustion problem, a laminar hydrogen-air flame, using finite rate chemistry. Our method addresses the challenges of approximating both the fast and slow timescales that arise in these applications. We show how a POD reduced model can estimate outputs of interest such as temperature, pressure, velocity components and concentration of species.

REFERENCES

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