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Acceleration of High-Fidelity Reactive Flow Simulations via Stiffness Reduction Based on Computational Singular Perturbation

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Numerical simulations of chemically reactive flows pose significant computational challenges due to stiffness and large dimensionality of the governing equations. In this work, we present an implementation of the Computational Singular Perturbation (CSP) solver within the KAUST Adaptive Reactive Flow Solver (KARFS) to accelerate detailed-chemistry Direct Numerical Simulations (DNS). At each grid point, applying the operator-splitting technique, the CSP solver removes stiffness *on-the-fly* and numerically integrates a non-stiff Reduced Order Model (ROM) of the thermo-chemical operator. This allows to advance the thermo-chemical state with an *explicit* numerical scheme making use of larger integration time steps, without sacrificing accuracy. The computational overhead associated with the evaluations of the Jacobian eigenstructures is effectively eliminated through a novel *online* hash mapping technique, which enables efficient reuse of the eigenstructures in the spatio-temporal domain. The approach was applied in DNS of laminar and turbulent ammonia–air premixed flames, resulting in a computational speedup–at comparable accuracy–over conventional Backward Differentiation Formula (BDF) methods.