Preconditioning of A High-Order, Fully-Implicit Compressible Flow Solver for Large-Scale Simulations of Multi-Physics Processes in Additive Manufacturing

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ABSTRACT

We present a new high-order, fully-implicit fluid dynamics solver for simulating compressible multi-material flows with phase change [1]. The work is motivated by laser-induced phase change applications, particularly the selective laser melting (SLM) process in metal additive manufacturing (AM). Simulations of the SLM process require precise tracking of multi-material solid-liquid-gas interfaces, due to laser-induced melting/solidification and evaporation/condensation of metal powder in an ambient gas. These rapid density variations and phase change processes tightly couple the governing equations, requiring a fully coupled monolithic framework. The governing equations are discretized in space up to 4^{th}-order with a reconstructed Discontinuous Galerkin method and integrated in time up to 5^{th}-order with *L*-stable fully implicit time discretization schemes (ESDIRK). The resulting set of non-linear equations is converged using a robust Newton-Krylov method, with the Jacobian-free version of the GMRES solver. Due to the stiffness of the underlying physics associated with stiff pressure waves and thermal and viscous/material strength effects, preconditioning of the linear solver is essential.

To enable convergence of the highly ill-conditioned linearized systems resulting from multi-phase problems, we employ a physics-based preconditioner (PBP), which utilizes a robust Schur complement technique on the physics-block systems. We investigate different splitting strategies and extensions of the method to the high-order and multi-material case. Different solver and preconditioning options within PETSc and HYPRE are considered on the reduced preconditioned systems. We demonstrate that our PBP-Newton-Krylov framework converges well on very stiff multi-physics problems and has excellent algorithmic and parallel scalability up to hundreds of millions of degrees of freedom and tens of thousands of CPU cores. Results are shown for classic problems in fluid dynamics as well for multi-material laser-induced phase change problems. Future model enhancements will incorporate material evaporation and rapid solidification associated with the SLM process.

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REFERENCES

[1] R. Nourgaliev, H. Luo, B. Weston, et al., "Fully-Implicit Orthogonal Reconstructed Discontinuous Galerkin Method for Fluid Dynamics with Phase Change", *J. Computational Physics (January, 2016)*. Vol. 305.