Tackling Compressible Turbulent Multi-Component Flows with Dynamic hp-Adaptation

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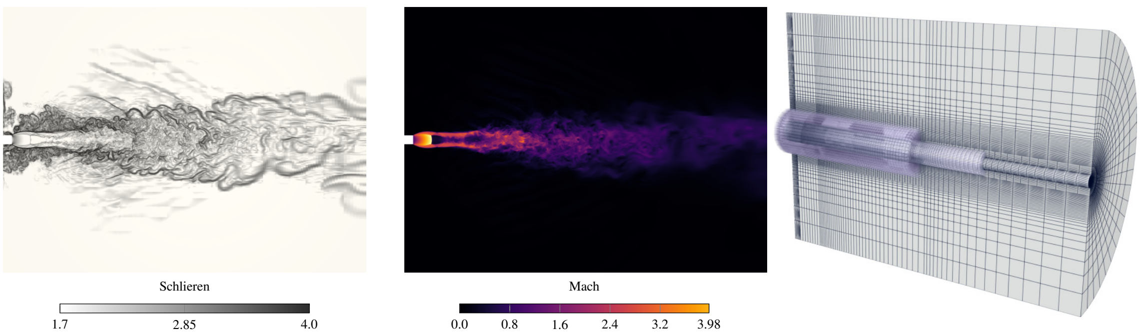
Turbulent multi-component flows are central to a wide range of engineering applications. A prominent example in the face of the climate crisis and the depletion of fossil fuel reserves is the adaptation of internal combustion engines to hydrogen. Here, a close understanding and accurate prediction of the high-speed injection and mixing of the hydrogen with air plays a critical role in controlling the combustion process. Simulating such flows presents significant challenges due to the nonlinear interactions of shock waves, turbulence, acoustics, and material interfaces, which span a wide range of spatial and temporal scales.
To tackle such flow problems, this talk presents an innovative dynamic hp-adaptive hybrid discretization that combines a p-adaptive Discontinuous-Galerkin Spectral Element Method (DGSEM) with a Finite-Volume (FV) discretization on h-refined sub-cell grids. Guided by an indicator, which evaluates the element-local modal solution representation, the hybrid DG/FV method leverages both the exponential convergence of the high-order DG approach and the robustness and precise shock-localization of the FV sub-cell scheme.
The hp-refined DG/FV operator was previously introduced for inviscid gas-dynamic problems in [1] and proved well suited for sharp-interface simulations of compressible droplet dynamics [2]. With the present talk, the adaptive discretization is extended to viscous multi-species flows and adapted for non-conforming grids, facilitating efficient mesh generation. A key challenge in this context is the computation of convective and dissipative fluxes at non-conforming element interfaces of mixed discretizations.
We assess the performance of the novel method in handling underresolved turbulence in the presence of shocks with the supersonic Taylor-Green benchmark [3], and demonstrate its multi-species capabilities on non-conforming grids through a triple-point shock interaction problem. Lastly, we showcase an implicit Large-Eddy simulation of a supersonic H_2-jet, following the setup of Hamzehloo et al. [4]. With the turbulent mixing of hyrdogen and air during the jet breakup as visualized in figure 1, we demonstrates the scale resolving capabilities of the method.



(a) Schlieren (b) Mach Number (c) Computational Domain

Figure 1: Implicit LES of supersonic H_2-jet, computed with the hp-adaptive hybrid DG/FV operator.

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[1] Mossier et al., Journal of Scientific Computing **91** (2022)
[2] Mossier et al., Journal of Scientific Computing **97** (2023)
[3] Chapelier et al., Physics of Fluids **36** (2024)
[4] Hamzehloo et al., International Journal of Hydrogen Energy **39** 21275-21296(2014)