An adaptive multiresolution framework applied to turbulent compressible reacting flows

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Turbulence – flame interactions are studied with a newly developed adaptive multiresolution code, which is open source and available on [1]. The numerical framework uses block-based structured adaptive grids with a wavelet thresholding multiresolution analysis as grid coarsening/refinement indicator. High computational performances is reached due to a hybrid data structure, fully MPI parallelization and space filling curve load balancing techniques. In a previous work it was shown that the thresholding error is controlled and scales nearly linear [2]. In the current work the adaptive multiresolution technique is applied to three dimensional reactive flow problems.

The numerical implementation is based on the fully compressible reactive Navier-Stokes equations, which are discretized in a conservative skew-symmetric form using explicit fourth order central differences and fourth order Runge-Kutta time integration schemes. Homogeneous isotropic turbulence is maintained due to low wavenumber linear forcing.

The chemical and thermodynamic quantities are calculated with the CANTERA library using a detailed chemical kinetics scheme for premixed hydrogen. Additionally reduced one- and four-step kinetics models are implemented for performance comparisons.

With this numerical approach several direct numerical simulations for different cases, e.g. propagating flame front, flame kernel growth, are performed. Different turbulent burning regimes are investigated in order to validate the numerical setup and computations. Flame-turbulence interactions are analysed and compared in phenomenology and statistical properties, with focus on the turbulent flame speed.

Results are investigated in terms of data compression rate and computational time. With these quantities the speed-up and threshold error in comparison to an equidistant fixed grid are calculated. Additionally the importance of different chemical and thermodynamic quantities for thresholding (mesh adaptation) is examined.

The aim of this work is to provide a new code, which is able to speed-up combustion computations for practical applications while controlling the errors due to the mesh adaptation and reach high performances in massively parallel processing.

Key words: adaptive multiresolution, wavelets, turbulence-flame interaction, detailed kinetics, fully compressible, direct numerical simulations, high performance computing, MPI parallelization

[1] `https://github.com/adaptive-cfd/WABBIT`

[2] Sroka, M., Engels, T., Krah, P., Mutzel, S. Schneider, K., Reiss, J.: An Open and Parallel Multiresolution Framework Using Block-Based Adaptive Grids, Active Flow and Combustion Control 2018, Springer, `https://doi.org/10.1007/978-3-319-98177-2_19`

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