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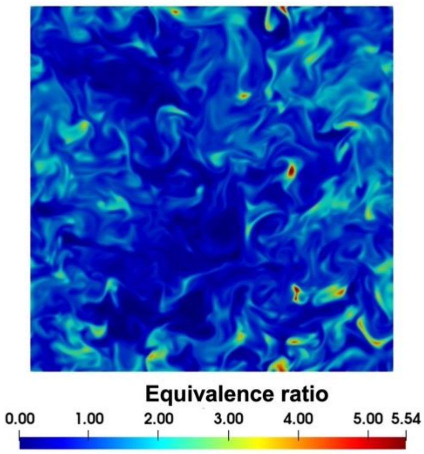
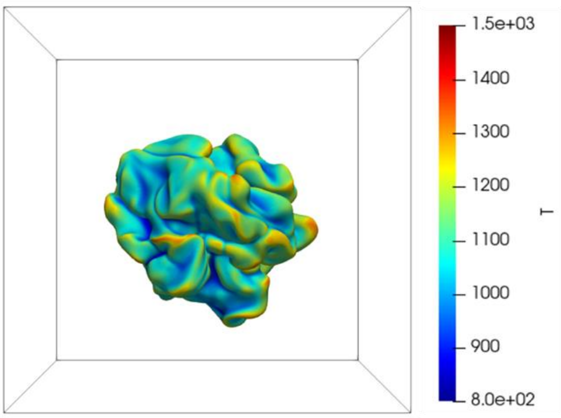
Bachelor/Master Thesis

Effects of equivalence ratio inhomogeneities on hydrogen flame kernel development

The flame kernel development is essential for the safety, stable operation, and high thermal efficiency of various combustion devices, such as aviation gas turbines, in particular during the relight and internal combustion engines. Most of the previous investigations of flame kernel development focused on the flame kernel interactions with turbulent flow fields for homogeneously distributed equivalence ratios. For direct-injection operations, the equivalence ratio field in the combustion chamber is often inhomogeneous, which could significantly influence the flame kernel development, especially when the kernel size is comparable to the length scale of the inhomogeneities.





In the proposed Bachelor/Master thesis, direct numerical simulations (DNS) of hydrogen turbulent flame kernels with inhomogeneous distributions of equivalence ratio will be performed and compared with the existing DNS data with a homogeneous hydrogen-air mixture [1]. First, small-scale DNS will be carried out on the RWTH cluster to finalize the simulation setups and validate the postprocessing tools. The full-scale simulation will be conducted on the supercomputers in computing centers in Germany. It is estimated that the DNS of a single flame kernel takes about 5 Mio. core-h generating about 20TB high-fidelity simulation data. In this study, 4 kernels will be simulated.

The supervisor possesses considerable proficiency in numerically investigating the development of flame kernels of both conventional gasoline fuels and hydrogen. The numerical framework and analysis tools have been previously developed and utilized in multiple studies [1-5]. The study is part of a DFG project, a collaboration between seven institutes at three German Universities, which includes numerical and experimental investigations.

Tasks:

- Generation of the inhomogeneous mixture field using the established framework
  - Considering the physical length and time scales, mesh resolution, and the computational cost

- Simulation of small-scale DNS cases using in-house code CIAO (on the RWTH cluster)
  - Specification of the timestep size, variables of interest, and visualization of the simulation results

- Simulation of the full-scale DNS using in-house code CIAO (on the supercomputers in computing centers, with the support of the supervisor)
  - Based on the results of the small-scale DNS

- Analysis of the effect of the equivalence ratio inhomogeneity on the early flame kernel development using the established postprocessing tools in CIAO and python scripts
  - Flame kernel growth rate
  - Flame surface area evolution
  - Tangential strain rate at the flame surface (only for master thesis)
  - Interactions with differential diffusion effects of hydrogen (only for master thesis)

Our Offer:

- Close supervision with integration into the research group
- A relevant, state-of-the-art research topic that can be adjusted to your interests

Requirements:

- Enthusiasm about programming and numerical modeling
- Interest in fluid dynamics and thermodynamics

Contact:

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References:

[1] H. Chu, L. Berger, T. Grenga, Z. Wu, H. Pitsch, Effects of differential diffusion on hydrogen flame kernel development under engine conditions, Proc. Combust. Inst. (2022)
[2] H. Chu, L. Berger, T. Grenga, M. Gauding, L. Cai, H. Pitsch, Effects of turbulence on variations in early development of hydrogen and iso-octane flame kernels under engine conditions. Combust. Flame, submitted for publication
[3] H. Chu, L. Berger, M. Gauding, H. Pitsch, Effects of dilatation and turbulence on tangential strain rate of premixed hydrogen and iso-octane flames under engine conditions, Proceedings of the European Combustion Meeting 2023
[4] H. Chu, M. Davidovic, L. Berger and H. Pitsch. A Comparison of Early Flame Kernel Development in Hydrogen/Air and iso-Octane/Air Mixtures under Engine Conditions, 18th International Conference on Numerical Combustion, 8-11 May 2022, San Diego, USA, 2022
[5] T. Falkenstein, H. Chu, M. Bode, S. Kang, H. Pitsch, The role of differential diffusion during early flame kernel development under engine conditions - Part II: Effect of flame structure and geometry, Combust. Flame 221 (2020)