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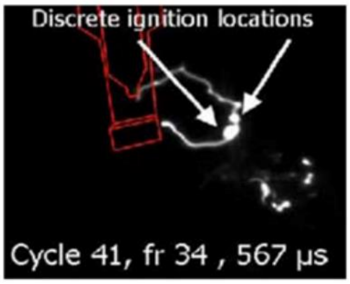
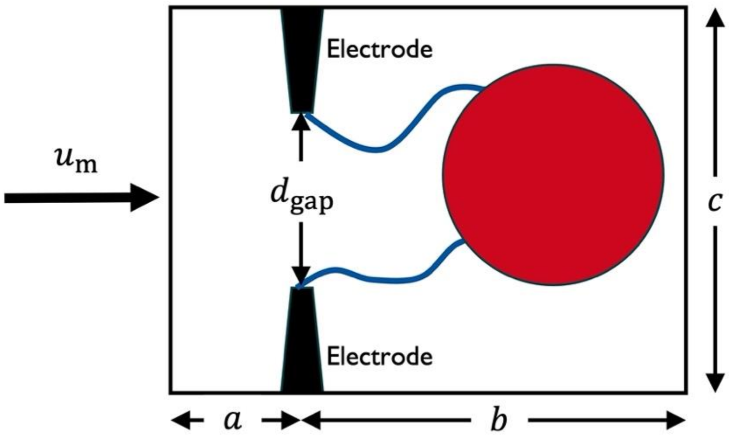
Bachelor/Master Thesis

Direct numerical simulations of plasma channel interactions with turbulence for hydrogen flame ignition

Understanding and prediction of ignition and early flame propagation are of practical importance for a range of applications such as aviation gas turbines, automotive engines, industrial furnaces, etc. Ignition is typically realized by a spark. During the discharge, a plasma channel is generated, which deposits energy in the gas mixture and leads to ignition. This plasma channel will be transported by the flow and thus the initial shape of the flame kernels is a result of the interactions of the plasma channel with the turbulence flows. This interaction is expected to have a strong effect on the early development of the flame kernels.





In the proposed Bachelor/Master thesis, direct numerical simulations (DNS) of hydrogen flame kernels will be performed, where the interactions of the plasma channel with turbulence will be considered. The plasma channel will be numerically described by Lagrangian particles, which are transported by the flow and deposit energy in the Eulerian gas mixtures. The analysis will focus on the effect of the resulting shape of the initial flame kernel on the growth rate of the flame kernels. 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 with a simplified ignition model without the consideration of plasma channels have been previously developed and utilized in multiple studies [1-5]. In the proposed study, the ignition model will be extended to consider the plasma channel. For this purpose, an existing validated plasma channel library will be integrated into our in-house code CIAO. The study is part of a DFG project, a collaboration between seven institutes at three German Universities, which includes numerical and experimental investigations.

Tasks:

- Integration of the plasma channel library in the in-house code CIAO
  - Testing using 2D DNS

- Specification of the DNS parameters and simulation of small-scale DNS cases using in-house code CIAO (on the RWTH cluster)
  - Considering the physical length and time scales, mesh resolution, numerical timesteps, and the computational cost
  - Determination of the 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, only for master thesis)

- Analysis of the effects of the initial flame kernel shape using the established postprocessing tools in CIAO and python scripts
  - Flame kernel growth rate
  - Flame surface area evolution (only for master thesis)
  - 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)