Institut Pprime UPR 3346 CNRS ISAE-ENSMA and University of Poitiers

PhD Thesis Proposal

High-fidelity data-driven construction of simplified models for flame dynamics and flame-generated sound

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General context

DECRESCENDO is a collaborative research initiative funded by ANR (Agence Nationale de la Recherche) and DFG (Deutsche Forschungsgemeinschaft) and involving the *Combustion Turbulente* and *Acoustique-Aérodynamique-Turbulence* groups at the Pprime Institute, alongside the *Laboratory for Flow Instabilities and Dynamics* at TU Berlin. The project addresses challenges in lean hydrogen combustion, with a specific focus on the acoustic phenomena generated by ultra-lean hydrogen/air flames. In contrast to other on-going projects dealing with thermoacoustic instability of flames in confined environment, it is focused on the root-cause of direct combustion noise and thus restricted to unconfined transitional and turbulent flames. Two PhD Thesis are funded by ANR in the framework of DECRESCENDO. One is focused on the analysis of high-fidelity numerical simulation results and the other on the analysis of experimental investigations.

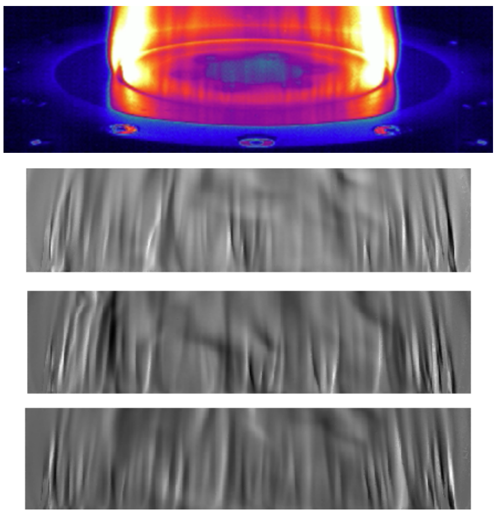

Fig. 1: Unstable annular flames experimental results.
Top: IR thermography (H_2O). Bottom: three instantaneous Schlieren images obtained on the annular burner studied by Figueira da Silva (2024).The wrinkles are characteristic of thermo-diffusive instabilities of lean hydrogen-air flames.

Brief description of the PhD proposal

The proposed PhD Thesis centers on (i) the high-fidelity numerical simulations of hydrogen/air flames and (ii) the analysis of the resulting databases to develop simplified models that capture flame dynamics and flame-generated sound. These models will be employed to design and validate sound-source identification techniques that will subsequently support experimental investigations, see Fig. 1, conducted on an annular burner (Figueira da Silva, 2024). The results of that study reveal coupling between thermo-diffusive flame instability and sound generation.

The PhD Thesis will involve the generation and analysis of high-fidelity numerical simulation databases of hydrogen flames in conditions comparable to those considered experimentally. The computations will be performed with the CREAMS in-house solver (Martinez-Ferrer et al., 2014; Boukharfane et al., 2018) which solves the compressible Navier-Stokes equations for multi-component reactive flows. CREAMS is coupled to CVODE and EGLIB libraries, thus permitting the use of state-of-the-art representations of detailed chemistry and molecular transport.

Preliminary DNS computations of planar flames will be performed to assess the choices of (i) the molecular transport description and (ii) the chemical kinetic scheme. For the latter, the relevance of simplified-optimized chemical schemes (Le Boursicaud et al., 2022) will be tested as a possibility for CPU cost reduction. From a more general viewpoint, the computations will aim to recover specific effects encountered in hydrogen-air flames, such as fuel consumption increase induced by thermo-diffusive instabilities (Berger et al, 2022 and Berger et al., 2023) or super-equilibrium temperature levels caused by local fuel enrichment of the mixture (Gicquel et al., 2004).

In parallel to the generation of data, dedicated postprocessing tools will be used for data reduction and the development of simplified models for the key processes underpinning sound generation (Cavalieri et al., 2019). Post-processing will involve modal decomposition and sound-source identification via inversion techniques (using the sound field to infer characteristics of the sound-generation mechanisms).

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