Ultra-lean hydrogen flames dynamics and their sound

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General information

Type of contract: Scientific fixed-term contract

Contract duration: 36 months

Expected date of employment: 1st October 2025

Working hours: Full time

Desired level of education: Master's degree and/or engineering school diploma

Work context

To combat climate change, hydrogen is being explored as a substitute fuel for aircraft engines, industrial furnaces, and heavy-duty motors. Such use of hydrogen would lead to systems that burn fuel-lean mixtures, raising challenges associated with the intrinsic instability of lean combustion processes and, where aircraft engines are concerned, combustion-related sound generation.

Motivated by these challenges, the PhD thesis, which is part of a partnership between Institut Pprime and TU Berlin (funded by the DFG-ANR project DESCRESCENDO), aims to investigate lean premixed hydrogen-air flames, which differ in many ways from their hydrocarbon counterparts: the high molecular diffusivity of hydrogen leads to unstable behaviour in lean combustion conditions; much of the heat release occurs at temperatures well below that of chemical equilibrium; broadband noise, associated with unsteady heat release, increases exponentially with equivalence ratio, but the underlying sound-generation mechanisms are not clearly understood.

Missions

The study will involve detailed experimental characterisation of an annular hydrogen flame and the sound it generates. The goal will be to understand and modelling the flow/flame dynamics and related sound-generation mechanisms. High-precision, spatiotemporally resolved, optical diagnostics will be used to explore and characterise the flame. Microphone arrays will be used to map the sound field. Synchronisation of the measurement systems will permit causal relationships to be established between the sound, flow and combustion dynamics. Data-reduction techniques will be implemented to identify key mechanisms and to guide the development of simplified models for the combustion and sound-generation processes.

Activities

The ultra-lean annular burner will be studied in the Institut-Pprime Banc MARTEL facility (Fig. 1). Measurements will be performed to cover the parameter space defined by Reynolds-, Lewis-, and Damköhler-number ranges: $300 \le Re \le 3000$; $0.3 \le Le \le 1.0$; $10^{-3} \le Da \le 50.10^{-3}$. Acoustic measurements will be made using an azimuthal microphone array. Flow/flame measurements will include time-resolved PIV (particle imaging velocimetry), high-speed schlieren photography and OH* chemiluminescence.

The databases will be explored using modal-decompositions and related signal-processing techniques whose objective is data-reduction that would reveal key dynamics associated with the combustion and sound-generation processes. The processed data will be used: (i) to provide a comprehensive characterisation of the flow, flame and sound fields as a function of the operating conditions; (ii) for the development of simplified models for the key combustion and sound-generation processes; (iii) for the validation of high-fidelity numerical simulations performed as part of a second DECRESCENDO PhD.

Competencies

We are looking for a highly motivated candidate who will fully commit to the project. She/he will have an aptitude for teamwork as the work will be co-supervised by researchers two Pprime research groups: Turbulent Combustion and Flame Structure (CT) and Aerodynamics, Acoustics and Turbulence (2AT). The PhD involves experimental and theoretical components; and it is multidisciplinary (acoustics and combustion). Candidates should therefore have a keen scientific curiosity, and be aware that working in a research laboratory requires autonomy and rigor.

- Knowledge of fluid mechanics (turbulence) and/or gas-phase combustion is desirable.
- Knowledge of acoustics and signal processing. Experience in the implementation of laser diagnostic techniques in fluid media would be welcome.
- Finally, some knowledge of hydrodynamic stability theory and linearized mean-field analysis would be a plus.

Constraints and risks

Work in the combustion laboratory with measuring equipment using lasers.

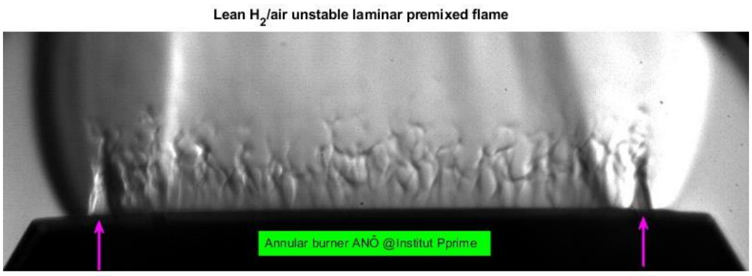

Figure 1 : Annular burner ANÔ at Institut Pprime: Instantaneous schlieren image of a premixed H_2-air flame at an equivalence ratio of 0.4 (left) and burner assembly at banc Martel (right).