Ph.D. Thesis Offer: Modelling of Non-Equilibrium Plasma Discharges for Hydrogen Combustion

Required Education: Master or Engineering School
Start date: September 2024
Mission duration : 36 months
Deadline for applications: 1 September 2024
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The Energy & Safety team, formerly known as the CFD-Combustion team, focuses on cross-disciplinary activities aimed at developing, optimizing and deploying scientific codes dedicated to advanced combustion simulations of industrial relevance. The team focuses particularly on flows encountered for aircraft, rockets, helicopters, car engines, turbines and more. As a result of such efforts, essential tools emerge for a wide range of applications, with the leitmotiv: let's calculate systems before we build them. More specifically, team members develop models and tools covering chemical reduction, turbulence, combustion, two-phase systems, combustion instabilities, etc., to meet both academic and industrial challenges. Thanks to its position, the team collaborates with numerous scientific groups, design offices of Cerfacs associates, and other Cerfacs teams.

CONTEXT

A major challenge for our society is to ensure access to reliable energy with low impact on the climate and the environment. To this end, sustainably produced hydrogen (H2) is a carbon-free alternative to the fossil fuels used today. However, the use of H2 as a fuel requires the adaptation of current combustion chambers in order to maximise efficiency, limit the emission of nitrogen oxides (NOx), and ensure safety. NOx emission regulations require the use of lean or ultra-lean premixed combustion for H2, which raises ignition and flame stability issues. The objective of this Ph.D., as part of the JETHPAC project (funded by ANR french government), is to develop the use of plasma discharges, more specifically Nanosecond Repetitively Pulsed Discharges (NRPD), an excellent candidate to i) guarantee a timely ignition after H2 injection in the combustion chamber, and ii) control combustion instabilities.

MISSION

The objective of this Ph.D is to understand how Non-Equilibrium Plasma (NEP) discharges can affects hydrogen combustion such as for ignition, flame stabilisation and pollutant emissions. For that purpose, the work has been divided in three major milestones, that have been defined to match with the measurements availability from the CAPS laboratory at ETH Zurich .

First, a thorough examination of the discharge in a flowing H2-air mixture will be conducted with both detailed chemistry tools (Cantera and Arcane)[1] and the AVBP code (http://www.cerfacs.fr/avbp7x) with its plasma extension[2, 3]. The chemical tools will be used to identify the major chemical pathways, based on idealised cases, that have to be retained in a reduced-order chemical model for Plasma-Assisted H2 Combustion (PAHC). One the other hand, detailed simulations of the plasma discharges in a cross flow will be used to investigate dimensional effects on the discharge properties. Then, the phenomenological model presented in [4] will be modified to account for the observations made from the simulations and experiments.

Second, Large-Eddy Simulation (LES) of Plasma-Assisted H2 Ignition in a flowing channel will be conducted using AVBP and the plasma LES closure developed in the first part of the Ph.D. Both flow parameters (velocity, turbulence, mixture, ...) and discharge parameters (frequency, energy, ...) will be investigated to provide recommendations for the use of NRP discharges for Plasma-Assisted H2 Ignition, both in term of reliability and safety.

Third, flame stabilisation will be investigated in a realistic burner shown in Fig. 1. Starting from a stable flame, acoustic forcing will be applied to study flame response to perturbations. NRPDs will be finally applied to investigate their potential to mitigate instabilities. Moreover, these simulations will be used to evaluate the impact of NRPD on NOx production that is a key issue in PAHC.

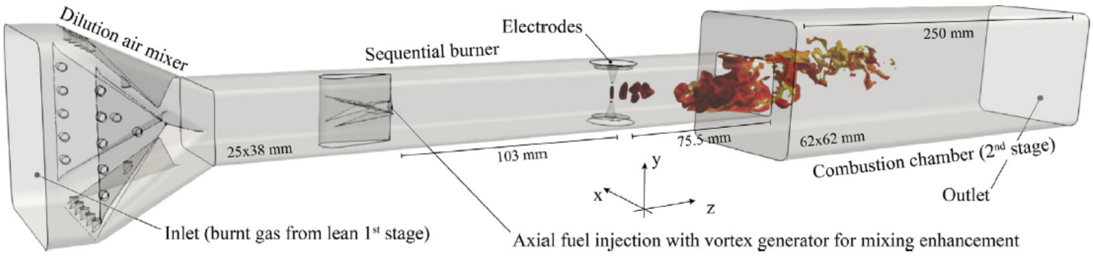

Figure 1: Plasma-stabilised methane-hydrogen flame in a sequential combustor [5].

References

[1] L. Cheng, N. Barleon, B. Cuenot, O. Vermorel, A. Bourdon, Plasma assisted combustion of methane-air mixtures: Validation and reduction, Combustion and Flame 240 (2022) 111990.

[2] L. Cheng, N. Barleon, O. Vermorel, B. Cuenot, A. Bourdon, AVIP: a low temperature plasma code (2022). `arXiv:2201.01291`.

[3] N. Barleon, L. Cheng, B. Cuenot, O. Vermorel, A. Bourdon, Investigation of the impact of NRP discharge frequency on the ignition of a lean methane-air mixture using fully coupled plasma-combustion numerical simulations, Proceedings of the Combustion Institute 39 (4) (2023) 5521–5530.

[4] N. Barléon, L. Cheng, B. Cuenot, O. Vermorel, A phenomenological model for plasma-assisted combustion with NRP discharges in methane-air mixtures: PACMIND, Combustion and Flame 253 (2023) 112794.

[5] Q. Malé, S. Shcherbanev, N. Noiray, Numerical study of plasma assisted combustion in a sequential combustor, Proceedings of the Combustion Institute 39 (4) (2023) 5447–5456.