PhD student position

Numerical simulation of decarbonized turbulent flames stabilized by plasma

Context

Hydrocarbon combustion, involved in more than 80% of the worldwide primary energy consumption, produces most anthropogenic CO_2 emissions. Because batteries exhibit a lower energy density than fuels, electrification will not replace combustion in the short term, especially in aircraft engines. Answering the climate change challenge, therefore, requires the decarbonization of combustion systems.

A solution for CO_2-free combustion is to burn e-fuel produced from renewable energy sources through, for instance, the electrolysis of water. Within this context, Airbus announced the simultaneous launch of three full hydrogen aircraft projects, which are expected to lead to a commercial program by 2035. This ambitious objective raises great scientific challenges.

Indeed, while e-fuel flames do not emit CO_2, they are characterized by high-temperature regions, which promote the formation of nitrogen oxides (NOx). A solution to limit the combustion chamber temperature is to decrease the mixture equivalence ratio. NOx production is well decreased, but the low flame temperature induces slower chemical reaction rates, often resulting in incomplete combustion. Such low-temperature regimes are also subject to flame instabilities and extinctions, causing safety issues [1].

An emerging solution to enable flame stabilization in leaner regimes, suitable to a wide range of combustion applications, is to generate electrical discharges at the flame basis. High-voltage electric discharges are generated between two electrodes located inside the combustion chamber. They locally generate a plasma, which interacts with the combustion. The Nanosecond Repetitively Pulsed (NRP) discharges [2,3] are particularly efficient; they allow the stabilization of lean premixed flames on several laboratory-scale hydrocarbon-air flames [4-6] and even in a test rig representative of a gas turbine environment [7] with plasma powers typically less than 1% of the power released by the flame.

The use of NRP discharges to enhance the stabilization of future decarbonized combustion chamber is promising but raises fundamental questions which deserve to be addressed by High Performance Computations. For that reason, EM2C combustion and plasma teams have developed a simplified description of these kinetic processes using a phenomenological model based on the observation that the main effects of nanosecond pulsed discharges are the electronic and vibrational excitations of nitrogen molecules and the dissociation of species by direct electron impact [8,9]. Preliminary results of the first simulation of turbulent flame stabilization by NRP discharges are shown in Fig. 1.

Objectives and work program

The objectives of this Ph.D. are to perform **High Performance Computations** of plasma-assisted hydrogen combustion by including complex chemistry effects into highly resolved turbulent reactive flow simulation. The impact of plasma on the combustion will be handled by improving the semi-empirical NRP discharge model developed by Castela *et al.* [8]. NOx formation being very sensitive to flow residence time and temperature, high-fidelity simulations of flow recirculation patterns induced by the discharges are mandatory. Challenges are multiple: i) the LES mesh size involved in practical combustor simulations is not fine enough to fully resolve all turbulent and chemical scales: subgrid scale models are then required; ii) the high-density energy deposited at the ultrafast (ns) scale causes issues if the numerical scheme retained is not adapted; iii) heat transfer between the electrode and the flow strongly influences the temperature field. iv) unlike hydrocarbon fuels, differential diffusion in H2-air flames must be considered. The retained solver is the high-order CFD code YALES2 [10] developed by the CORIA laboratory's combustion modeling group in Rouen (France). This Ph.D will rely on the following steps:

- Bibliography on plasma-assisted combustion simulations,
- Improvement of Castela's model [8] accuracy to account for burnt gases dissociation by the discharge
- Development of a turbulent combustion model for LES of plasma-assisted hydrogen flames.
- Large Eddy Simulation of a bluff-body flame stabilized by NRP discharges.
- Large Eddy Simulation of an aeronautical combustor fueled with hydrogen

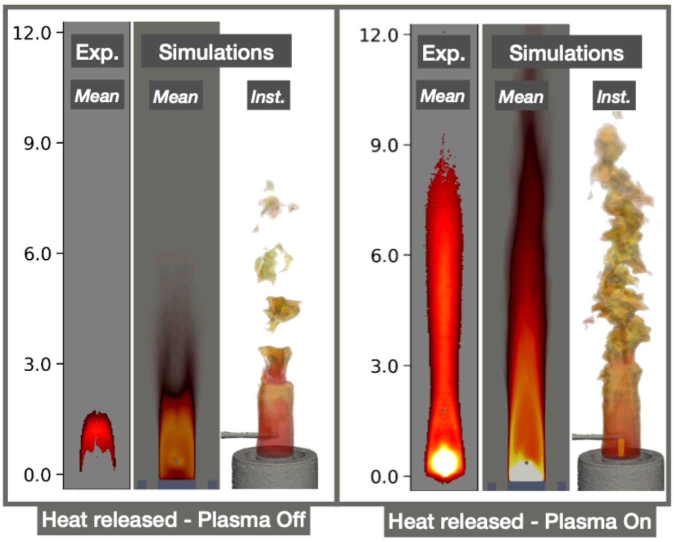

Figure 1*. Large-scale simulations of the stabilization of the plasma-assisted Mini-PAC burner. From Bechane (simulation) and Blanchard (experiments) PhD thesis (EM2C, ANR PASTEC, 2021).*

Skills required

Knowledge required in Numerical methods, Fluid Mechanics, Energetics, Heat transfer and Computational Fluid dynamics. This PhD is adapted to engineers and/or Master's degree in research.

Location and supervision

The doctoral studies will take place at the EM2C-CNRS laboratory located at CentraleSupélec, Université Paris-Saclay (Gif-sur-Yvette, France). The Ph.D. student will be co-supervised by Benoît Fiorina and Christophe Laux, professors at CentraleSupélec.

Application

Send a CV, transcript records and references to benoit.fiorina@centralesupelec.fr

References

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