Ph.D. Thesis

Experimental Study of Plasma-Assisted Combustion in a Hydrogen/Air Model Aeronautical Combustor

Summary:

The GreenBlue program (Greenhouse gas and pollutant emissions reduction using plasma-assisted combustion for a Blue planet) is a new 5-year program started in November 2021 at EM2C to develop carbon-free and carbon-neutral solutions for energy production using hydrogen or sustainable alternative fuels, with low NOx emissions. A promising way to design low-NOX combustion chambers for industrial applications consists in operating in the lean combustion regime. However lean flames are unstable but can be efficiently stabilized by Nanosecond Repetitively Pulsed (NRP) plasma discharges. The broad objective of this Ph.D. thesis is to study the stabilization of lean flames by NRP discharges in realistic combustion chambers operating with hydrogen/air. This work is divided into several steps. The first step will be to understand the effect of a plasma in a hydrogen/air canonical flame. The second step will be to demonstrate and analyze the effects of the plasma on a large-scale experimental facility representative of an aeronautical chamber.

Context:

Answering the pressing challenge of climate change requires rapid changes in energy production methods. Today, more than 80% of the primary energy production is based on the combustion of fossil fuels, which produce the majority of anthropogenic CO_2 emissions (IEA, 2020). Combustion also produces pollutants (nitric oxides-NOx, sulphur oxides-SOx, unburned hydrocarbons, soot) that must be kept below increasingly stringent limits. Europe's vision for aviation [1] targets 75% CO_2 and 90% NOx emissions reductions by 2050, relative to 2020 levels. Beyond aviation, CO_2 and pollutant emission reductions are also needed for power generation turbines, as well as domestic and industrial furnaces.

Because electrification cannot massively replace combustion in the short term, aircraft engine and turbine manufacturers are developing plans to switch to CO_2-neutral or CO_2-free combustion. CO_2-neutral combustion can be obtained by burning sustainable fuels (made from waste, sustainable crops, or from CO_2 and renewable electricity) and CO_2-free combustion is achieved by burning hydrogen or ammonia. Although these combustion strategies reduce or eliminate CO_2 emissions, the reduction of NOx emissions remains a major issue. A promising strategy to reduce NOx is to lower the temperature of flames by operating in the lean combustion regime. However lean flames are prone to instabilities and extinction, thus causing important safety issues and mechanical damage. It should be underscored that stoichiometric H_2-air flames burn at higher temperatures than hydrocarbon-air flames, and therefore lean flames are required for both H_2 and hydrocarbon combustion.

An emerging solution to stabilize lean flames, suitable for a wide range of combustion applications, is to assist combustion by means of high-voltage electrical discharges. The discharges locally generate a plasma that enhances combustion by producing active species in the flame. A particularly promising type of discharge is the Nanosecond Repetitively Pulsed (NRP) discharge [2,3], which has been shown to be particularly efficient in a wide range of conditions [4-7] with a plasma power typically less than 1% of the power released by the flame.

Objectives:

The objectives of the thesis are: (1) understand the effect of a NRP discharges on hydrogen/air flames (2) determine a strategy for reducing NOx in plasma-assisted hydrogen-air flames; (3) demonstrate the proposed strategy in a high-power hydrogen-air combustion chamber.

Work Program:

1. Study of a bluff-body lab-scale burner H_2/air stabilized with NRP discharges. This canonical configuration will be characterized by Optical Emission Spectroscopy and laser diagnostics. The experimental results will be compared with numerical simulations performed by another Ph.D. student.
2. Adaptation of a large-scale methane-air combustor representative of aeronautical injection systems to hydrogen/air (see Fig. 1).
3. Development and implementation of a plasma-assisted combustion (PAC) system on this large-scale hydrogen-air combustor (BIMER 2 – hydrogen).
4. Characterization of flame stability, combustion efficiency and NOx production on BIMER2-hydrogen. The experimental results will also be compared with numerical simulations performed by another Ph.D. student.
5. Proposition and implementation of control strategies for thermos-acoustic instabilities mitigation.
6. Recommendation for scale-up strategies

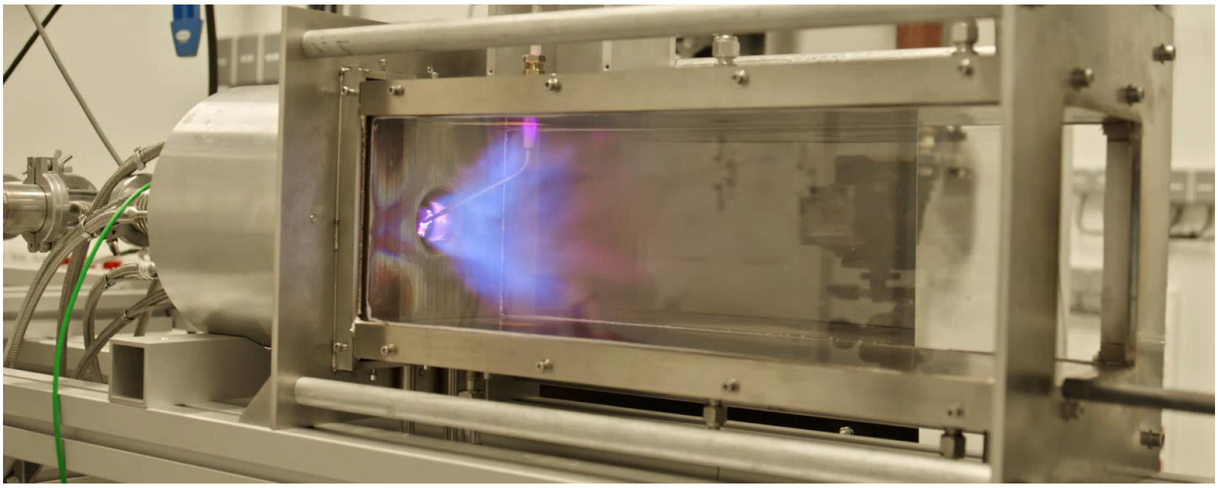

Figure 1. Lean methane-air flame stabilized by NRP discharge on the BIMER multipoint facility of the EM2C laboratory (Ph.D. thesis of Victorien Blanchard [11]). The facility will be adapted during this Ph.D. thesis to operate with hydrogen-air flames.

Skills required

The applicants must hold a Master's degree or equivalent in Engineering or Applied Physics. A background in plasma physics and/or combustion is preferred, but not required. The applicants should have a strong motivation for experimental physics and optical diagnostics. They should also have demonstrated teamwork abilities as the work will be performed in interaction with the large team of Ph.D. students, post-doctoral fellows, master students and permanent staff members involved in the ERC Greenblue program. The applicants should also have excellent oral and written communication skills in English, and be strongly motivated to contribute to solving the challenges associated with the energy transition. The Ph.D. position is supported by the ERC program GreenBlue.

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 Christophe Laux, professor at CentraleSupélec and Sébastien Ducruix, Senior Researcher at CNRS.

Expected start date:

The start date is flexible between October and December 2024.

To apply:

Please send CV, motivation letter and the contact of two references to:

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References:

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