Project objectives

The objective of this project is to analyze the physics of the turbulent combustion process downstream the bluff-bodies and to develop an efficient passive/active flow control method for optimization of the dynamics of the flames. The bluff-bodies are commonly used as parts of the injection systems in virtually all combustion chambers. They play the role of the elements stabilizing the flame shape and its localization. The project focuses on a deeper understanding of multi-scale mixing processes and their modulation (enhancement/suppression) by the intensification of interactions between large and small turbulent scales. These phenomena are still not fully understood and are now limiting the establishment of low-emissions and safe industrial devices (injection systems in combustion chambers, burners, engines, cauldrons, etc.). Particular attention will be put on the control of (i) inner and outer recirculation zones formed behind the bluff-bodies; (ii) flame lifting dynamics and flame stability; (iii) pollution reduction; (iv) strongly unsteady phenomena including the flame initiation (ignition), flame propagation phase or flame extinction, the phenomena that are crucial from the point of view of safety, reliability, environmental cleanliness and efficiency. The main novelty of the project is the combination and simultaneous use of the passive and active flame control methods, which will allow alteration of the local and global characteristics of the mixing process. The key outcome of the project will be a better understanding of turbulent mixing and combustion processes behind the bluff-bodies and guidance on how they can be optimized, e.g., sustained, intensified, or damp. The specific objectives of the present project are the following:

- To develop deeper knowledge on the fuel/oxidizer mixing processes and phenomena that are critical for the development of novel, efficient, and clean fuel use, i.e., ignition, extinction, flame propagation, and its stabilization mechanisms by auto-ignition or turbulent flame propagation.
- To develop and verify knowledge-based passive/active optimization tools, which will enable efficient tuning of mutual interactions between the flow/flame scales along a whole energy spectrum.

Research methodology

We will consider both the passive and active flow control techniques that will be applied both in a separate and combined variant. The former will rely on the shaping of bluff-bodies geometries and changing their wall topology. It has been shown in the past that non-reactive flows issuing from non-symmetric channels or surrounding sharp-edged, or flows over wavy surfaces characterize excellent mixing properties. We will verify to what extent this holds in reactive flows. Within the project, beside attempting to deeper the knowledge on the turbulent flames behind the bluff-bodies we will try to find their preferred shapes for varying fuel and oxidizer parameters (speed, composition, temperatures) depending on assumed optimization criteria (e.g., maximum/minimum lift-off height of the flame, maximum/minimum flame surface area, the most uniform temperature, etc.). From the point of view of better flame control under a variety of different flow regimes, the active control approaches seem to be much more flexible. Active methods involve energy input (excitation) whose type and level may be fixed (predetermined approach) or vary depending on instantaneous flow behavior (interactive approach). In this project, the active control will be obtained by a modulated excitation introduced to the flow by an axial and axial + helical (azimuthal) forcing. The research will be carried out using advanced CFD tools (SAILOR code and DNS/LES methods) and will be complemented by experimental research on a ready-to-use facility enabling mounting of variable shape bluff-bodies and equipped with a system for active flow modulation.

Expected impact of the research project on the development of science

Concerning the control of strongly unsteady combustion processes (e.g., flame stability, propagation, flame shape, auto/spark ignition) one should realize that they are indirectly but largely dependent on the mixing process. The auto-ignition, flame propagation, and stabilization are conditioned by the fuel/oxidizer mixing in high-temperature regions, whereas the spark ignition is dependent on whether the spark is placed in the region of well-mixed ignitable mixtures. It can be assumed that with the accurate and precise prediction of the mixing phenomena both the ignition processes, as well as flame propagation/stabilization will be efficiently controlled, and this is crucial for the efficiency and safety of many industrial devices. The ability to successfully changing the flame shape or altering its dynamics is very tempting and the works in this direction will offer new perspectives both for scientists and engineers.