1 Project objectives

The objective of the project is to build upon and contribute to the existing knowledge by (i) identifying the global instability phenomenon in flames with annular counterflow imposed, (ii) reporting and studying a newly recognized feedback mechanism involving the flame lift-off. The former allows further understanding of the global instability phenomenon through fundamental theoretical and numerical studies. Despite considerable research efforts in the past, the hydrodynamic instability phenomena are still not fully understood. The latter may ultimately provide the means to facilitate stable combustion in the early design stages of novel gas turbine combustors.

The annular counterflow consists of the central nozzle providing fuel and a larger co-axial nozzle sucking fluid from the surrounding of the central nozzle. It is engaged to manipulate the flow field by inducing global instability. The essential feature of global instability is the appearance of large coherent structures, e.g., toroidal vortex shedding. These contribute to the enhancement of the mixing process between fuel and oxidizer and the modulation of the flame's front. Both play an important role in flame lift-off. Lifting of a flame has two essential advantages. First, once the flame is in a lifted state, the risk of a flashback is largely eliminated. Second, the distance between the burner rim and the flame base constitutes a separation layer preventing the burner from thermal stresses or corrosion. The exact role of global instability in the transition between attached and lifted flames with the use of annular counterflow has not been elucidated so far. This project attempts to identify the underlying mechanisms with a hope for its possible use in practical applications.

Project specifically focuses on hydrogen-air combustion. Hydrogen is considered as a promising energy carrier but the burning of the hydrogen creates new challenges (e.g., flashback, NOx emission) which need to be understood. This project aims to better understand the hydrogen combustion characteristics and provide the capability for effective flame control with annular counterflow triggering global instability.

2 Research methodology

Within this project, the potential of the global instability phenomenon is employed to change the character of a combustion process. The focus is put on a counter-current configuration, which has been proven in the past to increase mixing efficiency and prevent flame blow-out. Non-premixed/premixed flames are considered under a variety of control parameters (speed, composition, temperature). Particular attention is put on: (i) influence of operating conditions (density/velocity field) on the onset of the global instability; (ii) multi-scale mixing enhancement due to coherent flow structures; (iii) flame dynamics and stabilization mechanism; (iv) pollution emission.

The research is performed by means of the spatio-temporal linear stability theory and high-fidelity simulation techniques (DNS/LES), which are reliable in predicting global instability. A thoroughly validated internal code (SAILOR) is used and further validation of the numerical results is based on experimental data available in the literature.

The theoretical and numerical study on global instability in non-reactive counter-current jets (passive mixing) prepares a set of parameters to perform numerical simulations for reactive counter-current jets (flames). These aim at physical understanding of the flame's response to global instability and yield the complete flame control strategy. DNS and LES are performed using an advanced numerical approach (discretization methods, combustion models, chemical kinetics mechanism, etc.) describing all relevant physical aspects of turbulent flames including both strongly unsteady phenomena as the auto-ignition or flame quenching as well as the radiative effects and thermal NOx formations.

3 Expected impact of the research project on the development of science

The successful project will open new avenues of research and engineering applications. Unprecedented flame control is expected to be achieved, thoroughly explained by conceptual methods. This novel control strategy and its understanding will radiate in future research on similar counter-current configurations or new ones.