EM2C, CNRS UPR 288

LABORATOIRE ÉNERGÉTIQUE MOLÉCULAIRE & MACROSCOPIQUE, COMBUSTION

Energy and transportation have become significant issues likely to disrupt the general organization of society severely. The scarcity of oil, the rational use of fossil fuels, reducing emissions, developing renewable energies, and climate change risks pose many scientific questions. High-level academic research on energy and combustion from molecular scales to more macroscopic scales and applied studies, in partnership with leading companies and research centers in the field of transport and energy, allows the EM2C laboratory from CNRS at CentraleSupelec, to contribute significantly to the advancement of knowledge of these problematic issues.

Energy research at the heart of the Twenty-First Century industrial challenges

The laboratory's research activities are organized around three axes: combustion, non-equilibrium plasmas, physics of transfers, and transverse action in Applied Mathematics.

Combustion activities focus on the understanding, control, simulation, improvement, and optimization of combustion. The objectives are a better understanding of basic mechanisms and their interactions simultaneously developed through experimentation, modeling, and high-performance numerical simulations. This research is also based on innovations in diagnostics, sensors, actuators, control methods, and means of simulation.

Research on non-equilibrium plasmas includes fundamental studies using advanced optical diagnostics of the hydrodynamics and chemical kinetics of non-equilibrium plasmas at atmospheric pressure. In parallel, we consider applications to the fields of energy (ignition and stabilization of lean mixtures of fuel, hydrogen production), aerodynamics, atmospheric re-entry (VUV radiation, ablation), bio-decontamination.

Research conducted in the physics of transfers' team is around the energy transfer by radiation in gaseous media, transfers in porous media, and nano-thermal sciences. By combining fundamental approaches and the development of effective heat transfer models, this research addresses scientific and technological barriers related to applications as diverse as atmospheric re-entry spacecraft, transfer within the core of a nuclear reactor, or nanomaterials.

Transversal action in applied mathematics links fundamental mathematical and numerical tools on the one side and applications on the other side to provide solutions when stumbling blocks are to be found. Mathematical modeling, numerical analysis, scientific computing, and high-performance computing (HPC) improve the resolution of complex problems such as multi-phase flow simulations. Strong interaction with experimental researchers in the laboratory is also used to validate the developed models and codes and an in-depth understanding of the studied physical phenomena.

EXAMPLES OF STUDIES

Progress have been made for the development of reduced order models of disperse two-phase flows, where equations are filtered, so that only large scales are resolved. First, an original mathematical method, using an infinite sum of Ornstein-Uhlenbeck processes, has been developed to construct stochastic models aiming at reproducing the intermittency, which are phenomenon, corresponding to violent fluctuations of the dissipation field of the turbulent flow. This formalism allows not only to unify the writing of the existing processes but also to develop a new one, more versatile and more efficient in computation time. Moreover, a new kinematic model based on divergence-free wavelets has been proposed, to recover the properties of the unresolved scales. This allows to recover the heterogeneous spatial distribution of inertial particles in a turbulent flow.

In collaboration with Rodney O. Fox, two quadrature-based moment methods were developed for the description of population of particles such as droplets, bubbles or soots. One is the hyperbolic quadrature method of moments (HyQMOM), which is a globally hyperbolic velocity moment method, able to describe phenomena like particle trajectory crossing, a key point for the accurate prediction of the density of inertial particles when using Eulerian models. The other one is the generalized quadrature method of moments (GQMOM), which generalizes QMOM, used for the description of the size polydispersion of the particle population. GQMOM provides a more accurate moment method than QMOM, at nearly the same computational cost.

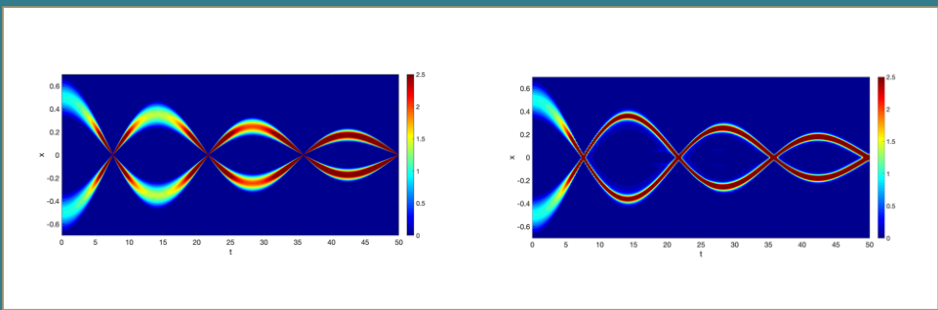

Fig.1: Number density for the analytical solution (left) and simulation with HyQMOM using 5 moments (right) of two crossing jets.

Progress have been made for the simulation of the acceleration and transition from deflagration to detonation of hydrogen/air flames, which is critical for nuclear safety. A high-order numerical solver was developed. Coupled to multiresolution techniques for mesh adaptation and immersed boundary methods for non-trivial geometric configurations with structured meshes, this allows to accurately capture the different stages of the flame acceleration and the transition to detonation and to reproduce the experimental observations.

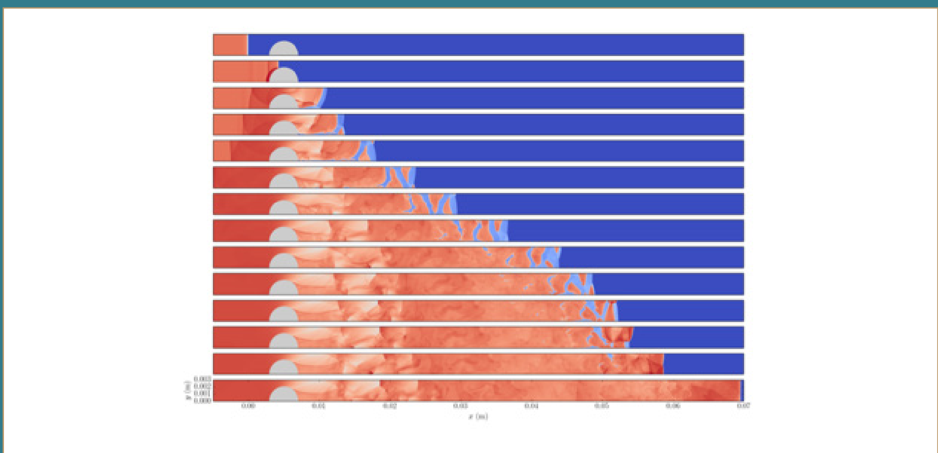

Fig.2: Temperature field evolution illustrating the detonation re-initiation.

A sharp interface approach was developed for computing two-phase flows with surface tension and phase change in the low Mach regime, where conventional compressible solvers lose accuracy. High-order approaches for interface advection and curvature estimation were proposed, as well as a new low Mach correction, able to recover a good asymptotic-preserving property, in the context where the interface is treated as the contact discontinuity via the Ghost Fluid method for a sharp interface. Several numerical test cases have been employed to validate and improve the present numerical approach's performance.

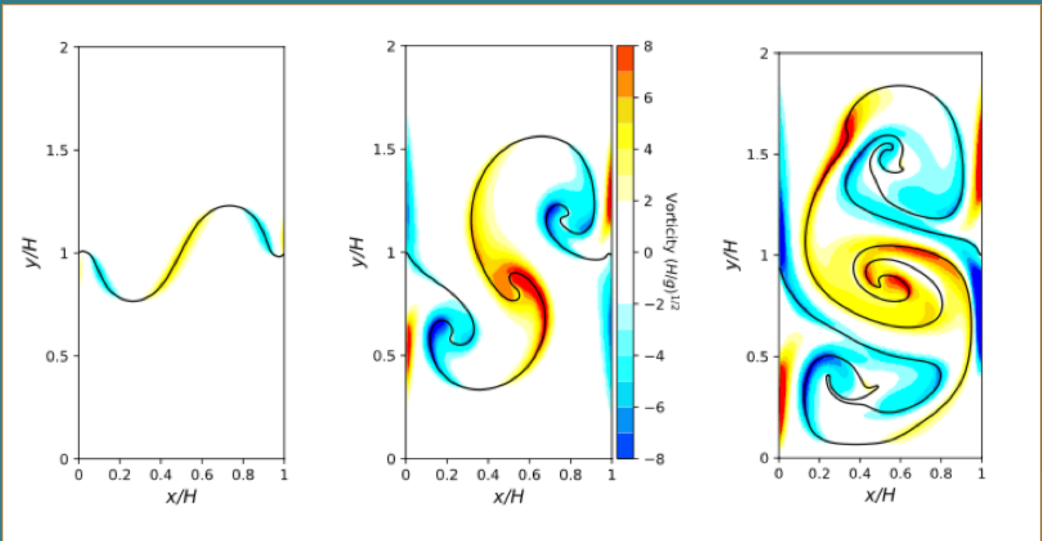

Fig.3: Vorticity of Rayleigh-Taylor instabilities obtained with the present compressible Level-Set scheme, at three dimensionless times: (t= 1, 3, 5). The black lines show the interface.*

The path towards carbon-free aeronautical propulsion and power generation necessitates the adoption of disruptive technologies and new fuels. Among them, hydrogen constitutes an interesting option because its combustion in air produces no carbon compounds. However, hydrogen flames raise many difficult issues: their high burning velocity promotes flashback, and their elevated adiabatic temperatures promote NOx emissions. To control these two phenomena, hydrogen and air must be quickly premixed to avoid hotspots, and the mixing has to be lean to reduce the flame temperature and NOx formation. These items are investigated in a laboratory scale test combustor (SICCA). This system, used to investigate the dynamics of swirled flames, has been equipped with a novel hydrogen injector operating in a lean direct injection mode (LDI). This unit uses a cross-flow injection to obtain a balance between premixing (to reduce NOx emissions) and resistance to flashback (for safety and operability issues). Parametric studies performed to investigate the behavior and structure of the flame throughout the operating domain have uncovered regions where the flame is detached from the injector and operates in a stable manner and regions where dynamical phenomena are manifested leading to combustion instabilities. Lifted flame configurations have been identified as promising candidates for further investigations that will include NOx emissions measurements and systematic determination of Flame Describing Functions, to assess their potential dynamic behavior. The novel injector will then be tested in the annular chamber MICCA for a complete assessment of the hydrogen-air flames' dynamics in a more realistic annular configuration.

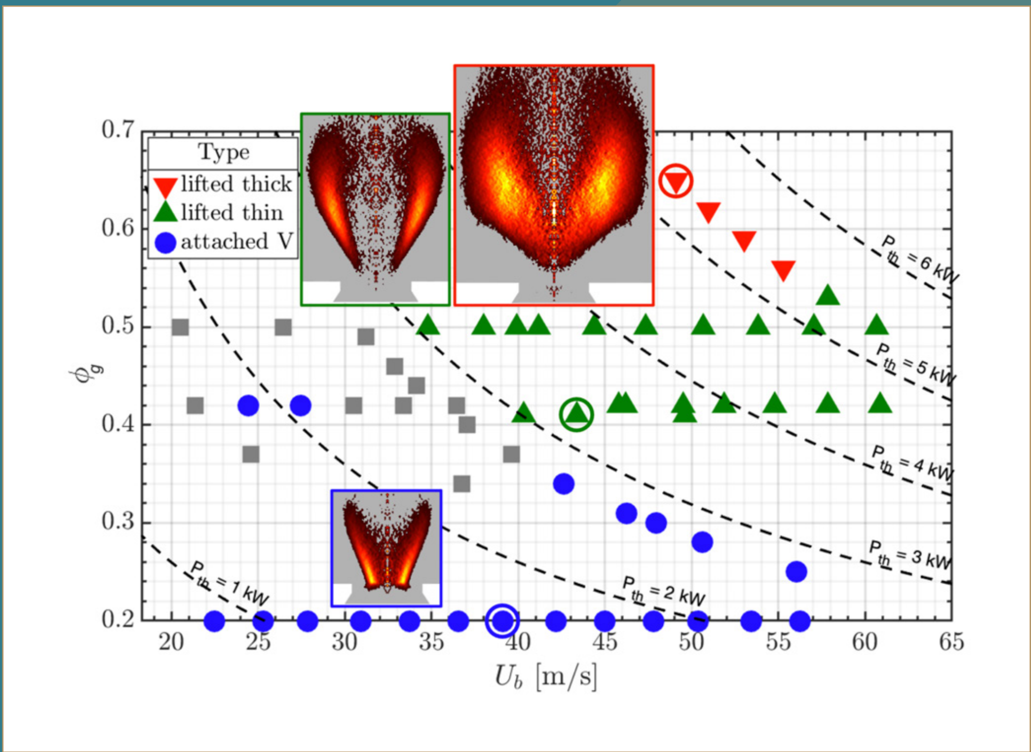

Fig.4: Map of the operating domain of SICCA using the CFI-X1 injector. Grey symbols correspond to unsteady operating points. In the higher thermal power range the flames are detached from the injector and are less sensitive to instabilities.

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Key figures

• Professors, Associate Professors & Researchers	31
• Engineers & Administrative staff	14
• PhD Students	51
• PostDoc	1
• Visiting Professor	1
• Publications of the year (WoS)	40

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