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Large Eddy Simulation of Flameless Combustion

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Context

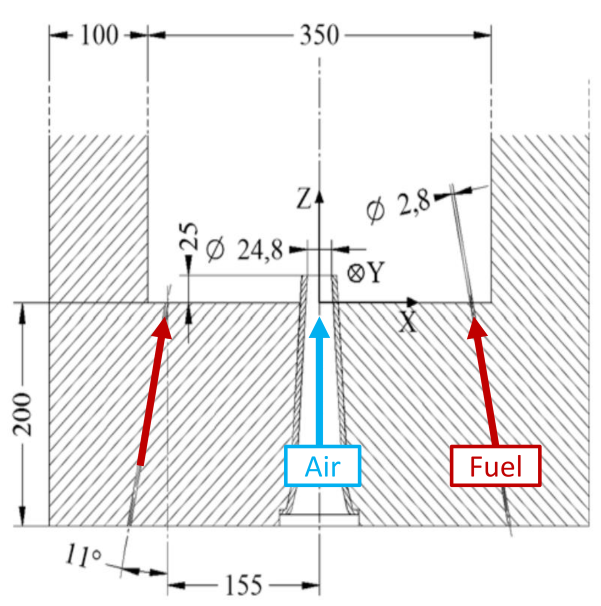
Flameless combustion, combining low pollutant emissions (e.g. NOx) with high combustion efficiency, is heavily used to design industrial burners. Internal recirculation of flue gas leads to high dilution of the reactants. This leads to a larger reaction zone and local temperature peaks are damped. Thermal Engineering and combustion department owns three flameless burners fed with air and gaseous fuel, for which it exists experimental data. Up to now, only RANS simulations with reduced reaction mechanisms have been performed. The aim is thus to go further into physical modeling.

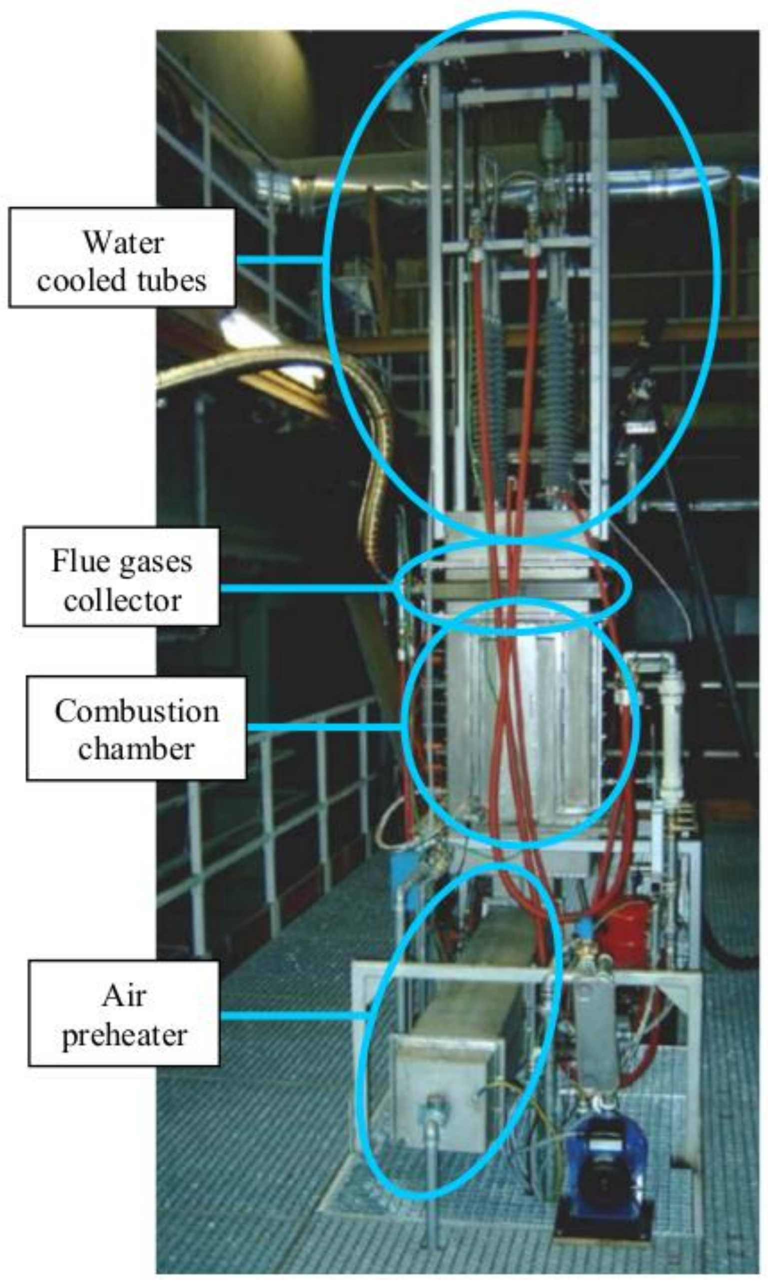
Objectives

- Numerical simulations of flameless turbulent combustion with the Large Eddy Simulation (LES) approach using OpenFOAM®
- Model accurately the flow and the combustion physics by carrying out complex multi-physics simulations (turbulence, detailed chemistry, radiation)
- Applications : Flameless furnaces

Furnace

- Power : 30 kW
- Dimensions : 0.35 m x 0.35 m x 1 m
- Flameless burner
- Furnace temperature control



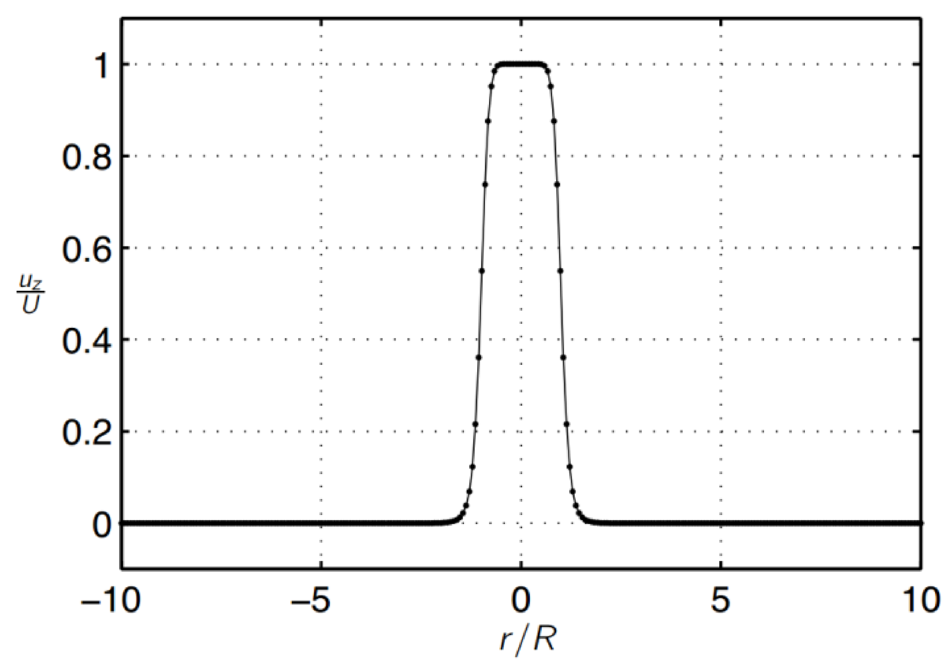


Current investigation

- Direct numerical simulation (DNS) of a confined turbulent jet
- Geometry close to the 30 kW furnace
  - Simplified configuration = box : L x L x 3L
  - Fine discretization : 256 x 256 x 1024 ≈ 67 x 10^6 cells
- Setup
  - Reynolds number = 5000 (based on available computational power)
  - Simulated period ≈ 10 x convective time
  - Preliminary work : incompressible flow (low Mach number)
  - Inlet jet velocity modeled by a hyperbolic tangent function with momentum thickness θ

$$f(r) = \frac{1}{2}\left(1 + \tanh\left(\frac{R}{4\theta}\left(\frac{R}{r} - \frac{r}{R}\right)\right)\right)$$

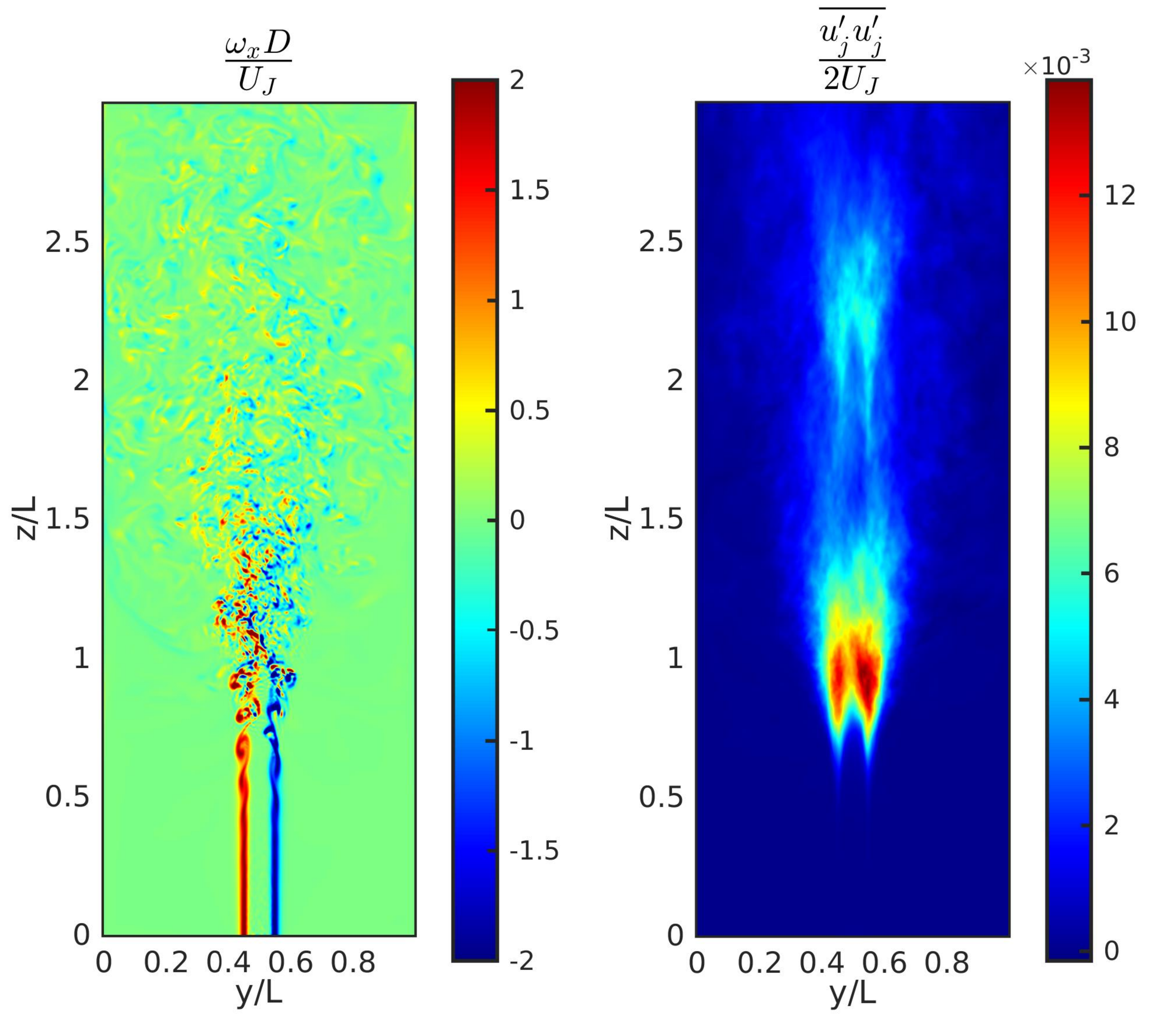
$$\begin{cases} u_x = I \times a_x(r,\varphi) \times f(r) \\ u_y = I \times a_y(r,\varphi) \times f(r) \\ u_z = U_J \times (1 + a_z(r,\varphi)) \times f(r) \end{cases}$$



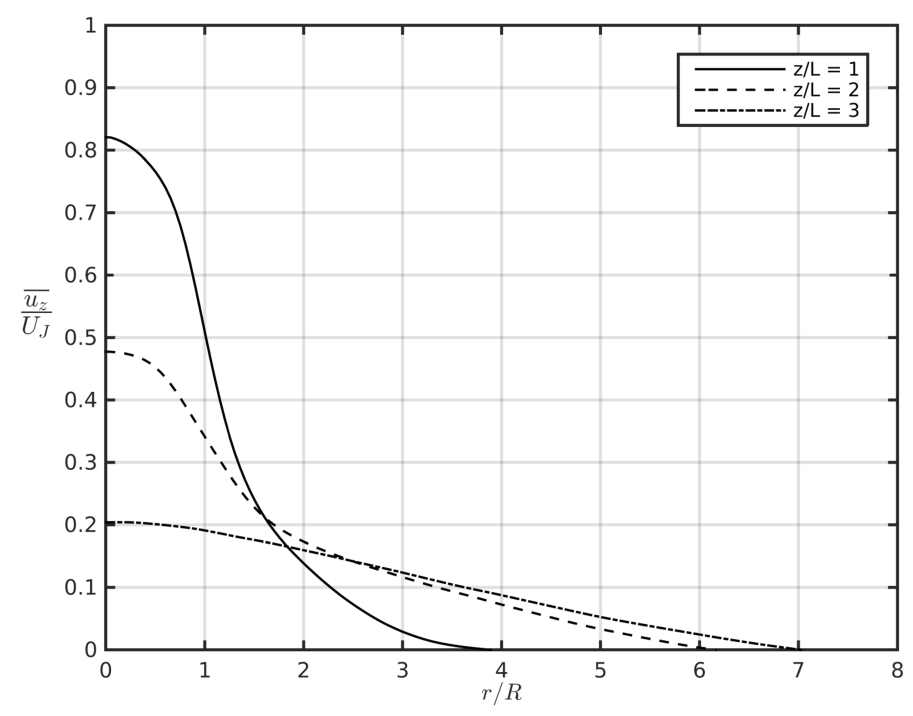
- High-performance computing
  - Massively parallel computations (computations using 256 processors)
  - CECI (Consortium des Equipements de Calcul Intensif)

Results

- Dimensionless transverse vorticity component and turbulent kinetic energy



- Axial velocity profiles at three locations



- A procedure was developed in OpenFOAM® to run the DNS of a low Re turbulent jet and the results are promising

Perspectives

- Carry out the simulation of the same jet taking compressibility effects into account
- Consider LES at higher Reynolds number of reacting flow with detailed tabulated chemistry (e.g. TDAC)
- Perform simulations with others/more complex geometries

[1] S. Murer, B. Pesanti, P. Lybaert, Characterization of flameless combustion of natural gas in a laboratory scale furnace, 2015

[2] D. Lupant, B. Pesanti, P. Lybaert, Influence of probe sampling on reacting species measurement in diluted combustion, Experimental Thermal and Fluid Science, 516-522, 2010

[3] F. Contino, Tabulation of Dynamic Adaptive Chemistry, Experimental analysis using ethyl esters and development of a method to include detailed chemistry mechanisms in numerical simulations, Chapter 5, Mai 2011

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