Lattice-Boltzmann Modeling of Supercritical Flows

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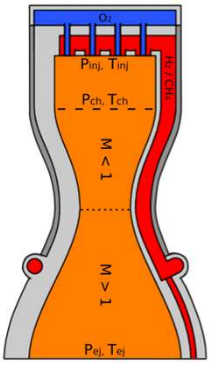


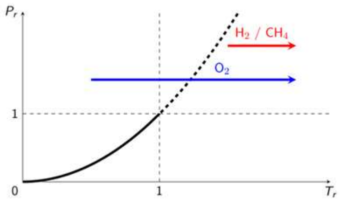
Objective : Numerical modeling of regeneratively cooled rocket engine combustion chamber

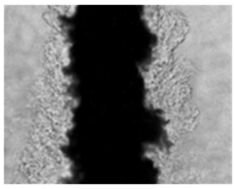
Challenges :

- Novel numerical method
- Supercritical fluids
- Turbulence
- Combustion

What is a Supercritical Fluid ?

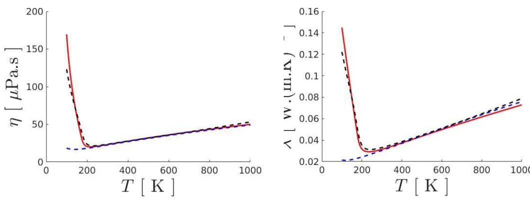
Imagine a droplet without any interface nor surface tension …





Supercritical break-up

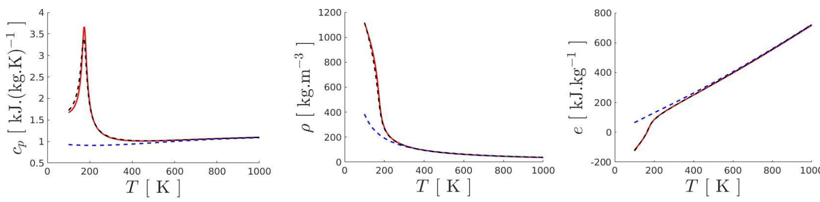
Transport : Chung's Correlation



Red: experiments | Blue: ideal gas
Black: Chung's correlation

Thermodynamics : Cubic Equation of State

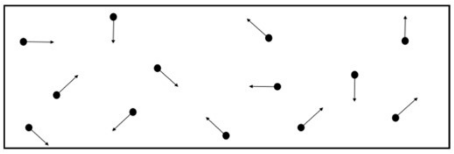
$$p = \underbrace{\frac{RT}{V_m - b}}_{\text{Répulsion}} - \underbrace{\frac{\Theta(T)}{(V_m - V_{m,1})(V_m - V_{m,2})}}_{\text{Attraction}}$$

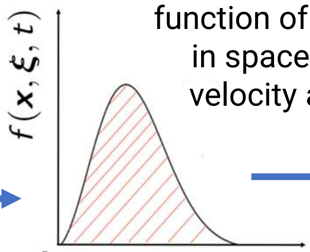


Red: experiments | Blue: ideal gas | Black: Cubic EOS

The Lattice-Boltzmann Method

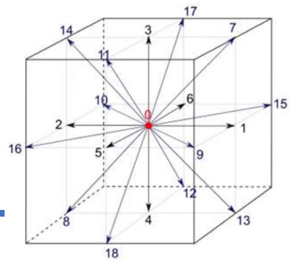
Kinetic theory of gases





Particle distribution function of location in space, particle velocity and time

Discretization of the velocity-space



Advantages :

- Highly parallelizable, so well-suited for clusters
- Quick meshing procedure due to cubic lattice

➔ Up to 10 times faster than classical solvers for industrial combustion applications !

Discrete-velocity Boltzmann equation

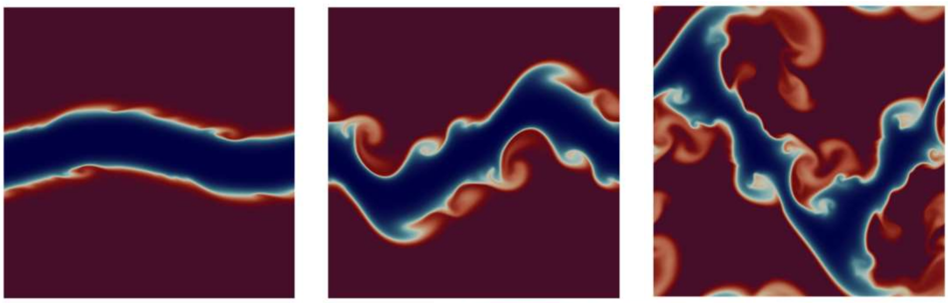
$$\frac{\partial f_i(\boldsymbol{x}, t)}{\partial t} + \boldsymbol{c_i} \cdot \vec{\nabla} f_i(\boldsymbol{x}, t) = \Omega_i(\boldsymbol{x}, t)$$

Non-local but exact | Local

Numerical Experiment : H2/O2 Double Shear Layer

Run on different mesh sizes

- Stable even for coarse meshes
- Convergence of order 2
- Captures pseudo-boiling



Density [kg / m³] :

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