

Effects of Navier-Stokes Characteristic Outflows : modeling for transverse flows

Current Objectives

- Highlight current limitations of outflow treatments.
- Decrease flow distortions at open boundary conditions.
- Allow reduction of computational domain size.
- Improve the understanding of NSCBC¹.

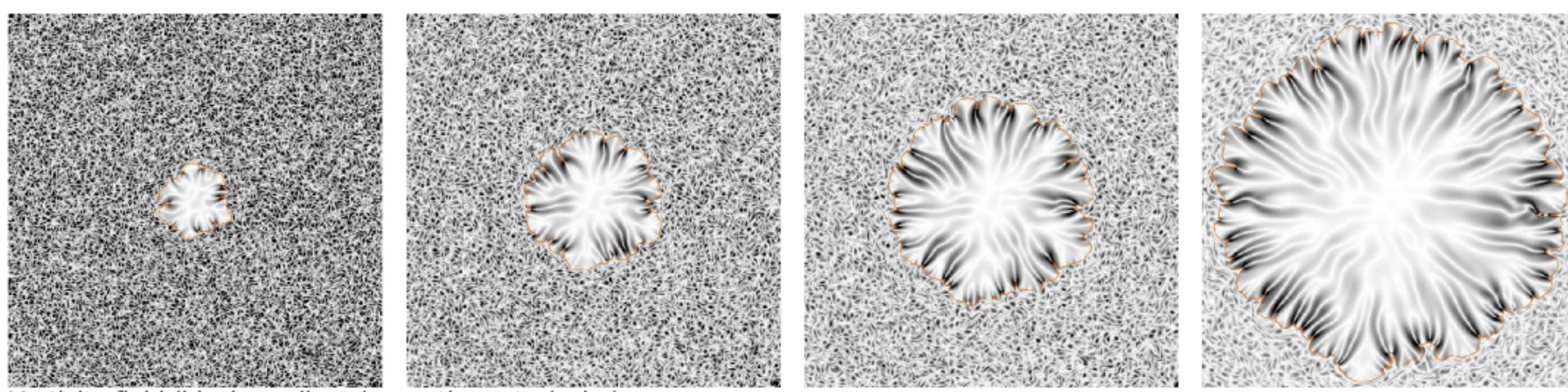
¹Navier-Stokes Characteristic Boundary conditions

Main concerned bibliography

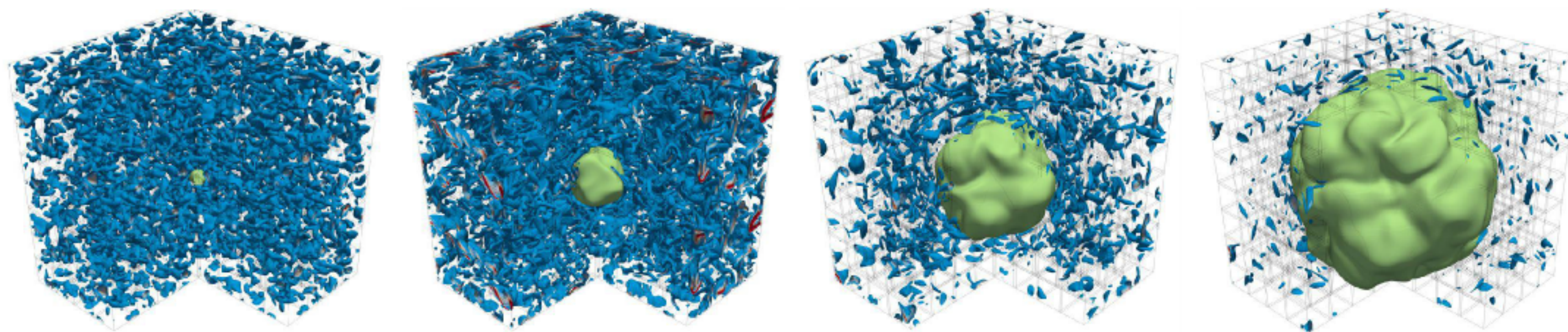
- NSCBC :**
Poinsot T, Lele S. Journal of Computational Physics (1992).
- 3D-NSCBC :**
Yoo CS, Im HG. Combustion Theory & Modelling (2007).
Lodato G et al. Journal of Computational Physics (2008).
- 3D-NSCBC-TOM :**
Albin E, D'Angelo Y, Vervisch L. Computers & Fluids (2011).

DNS of expanding flames : Effects of 3D-NSCBC open boundary conditions

Cylindrical and spherical expanding turbulent flames (20cm)² vs (3cm)³

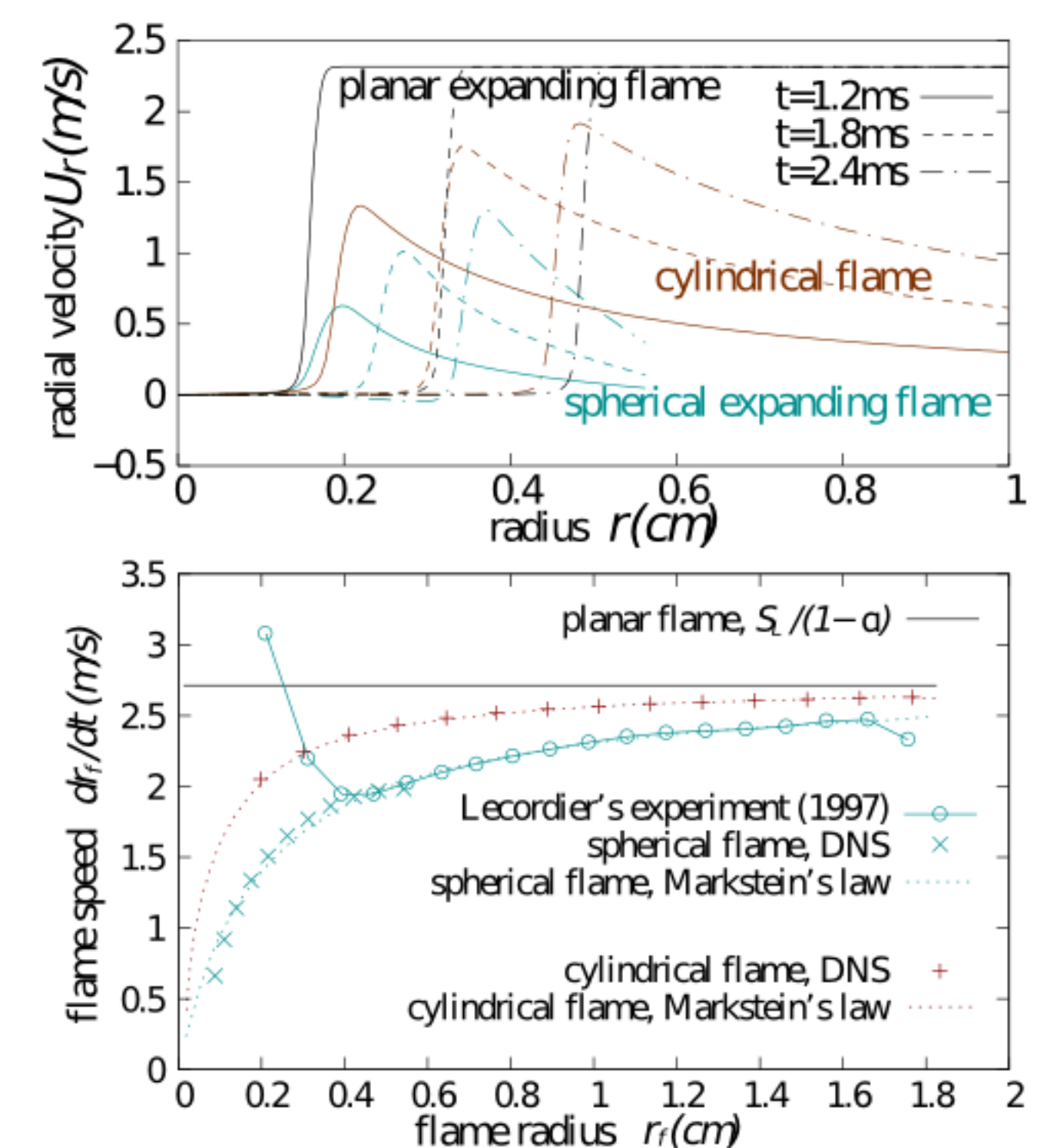


Vorticity field (black gradients), reaction rate (color)



Vorticity field (red to blue), reaction rate (green)

Laminar expanding flames



C₃H₈/Air
stoecho

Observations :

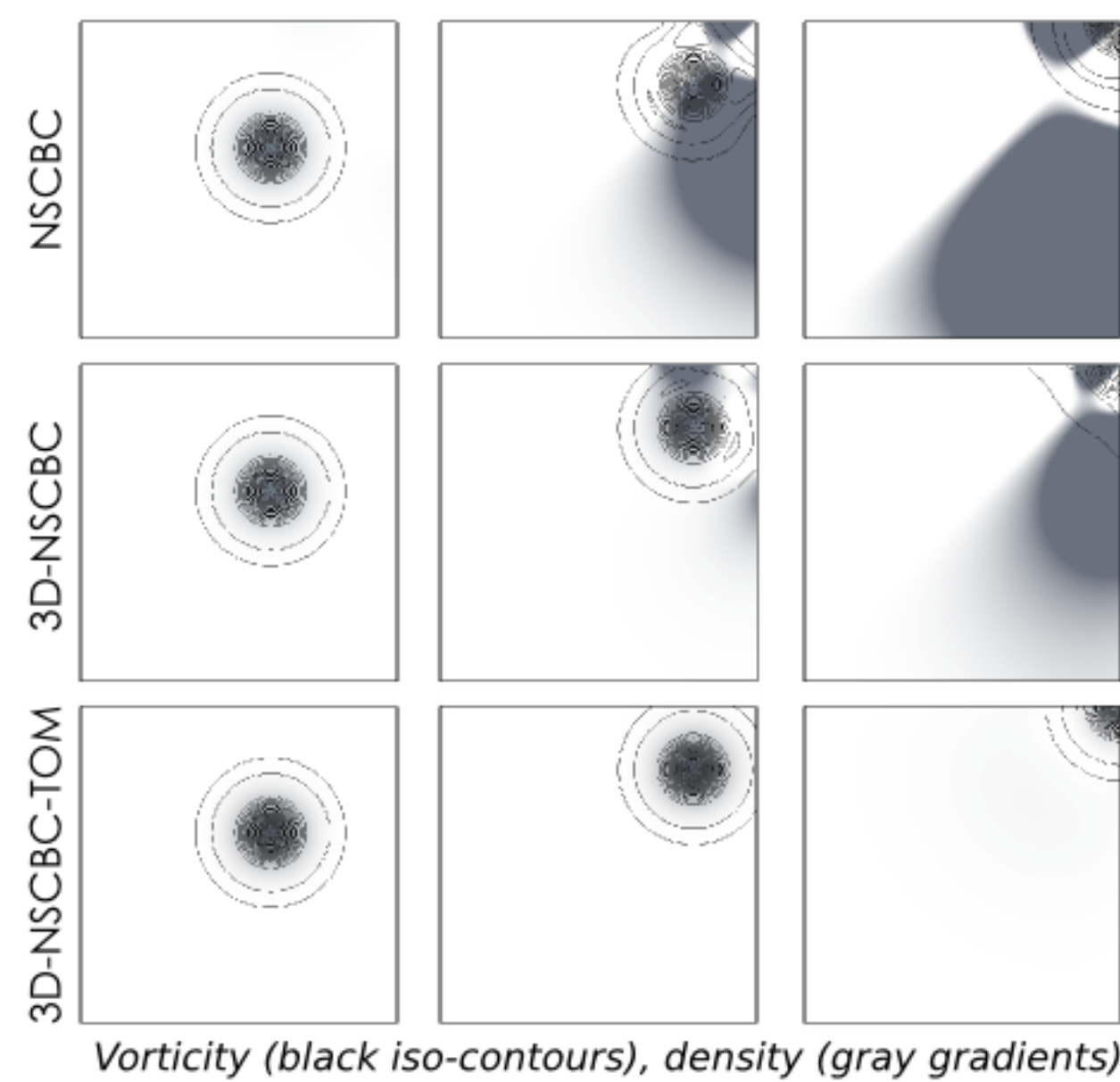
- Outflows generate spurious vorticity (in particular near corners or edges).
- Spherical turbulent flames generate much more instabilities than cylindrical turbulent flames.
- Flames become square shaped

Matching reasons :

- Negative velocities at outflows generate instabilities. The outflow amplifies the backflow.
- Burnt gases push less vortices in the spherical configuration. (consumption speed smaller, faster decrease of radial velocity, see curves)
- The backflow at outflows distorts the flame. 3D-NSCBC outflows is not pertinent for transverse flows (see below).

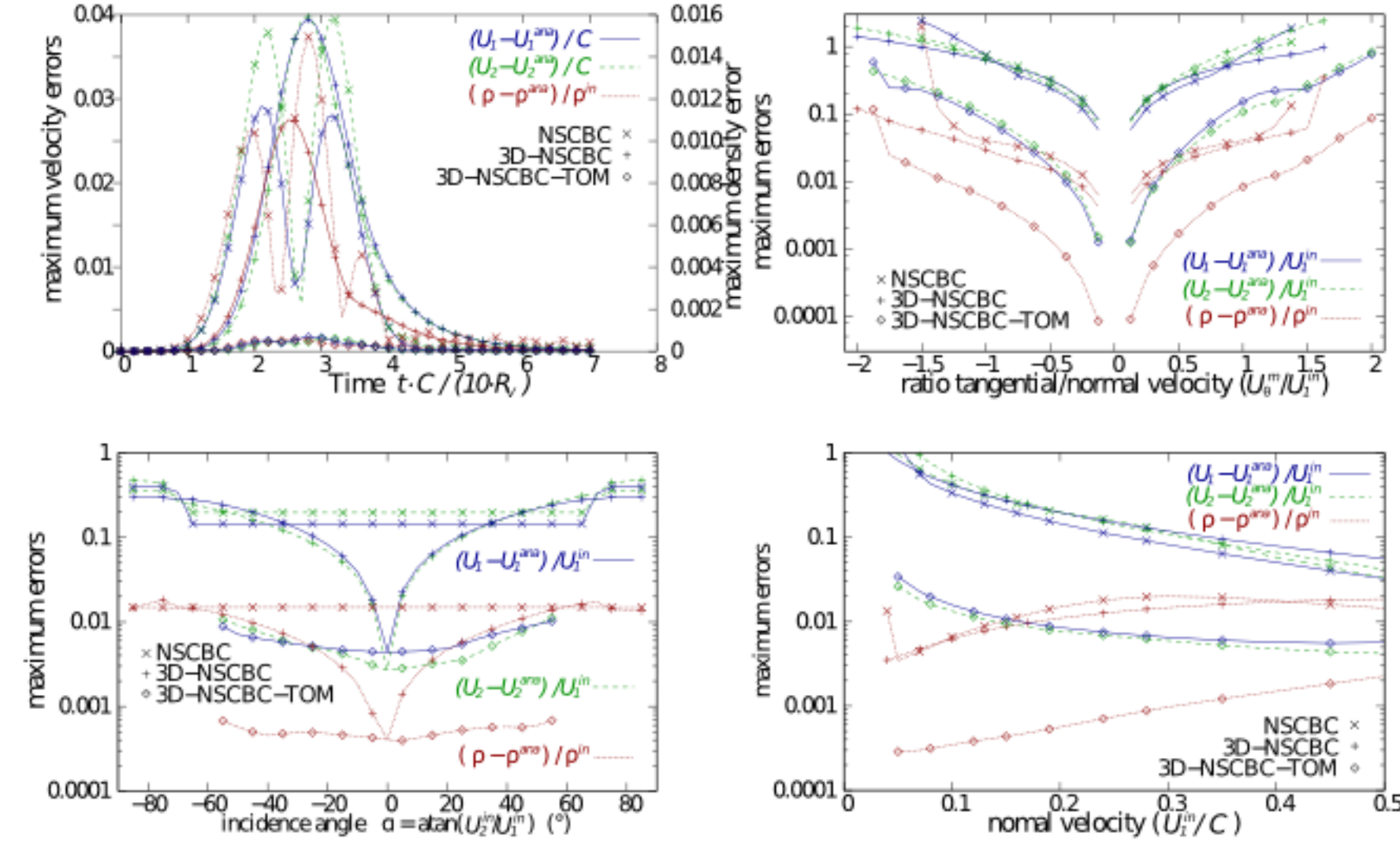
3D-NSCBC-TOM treatment for transverse flows

Outgoing vortex through the upright corner :

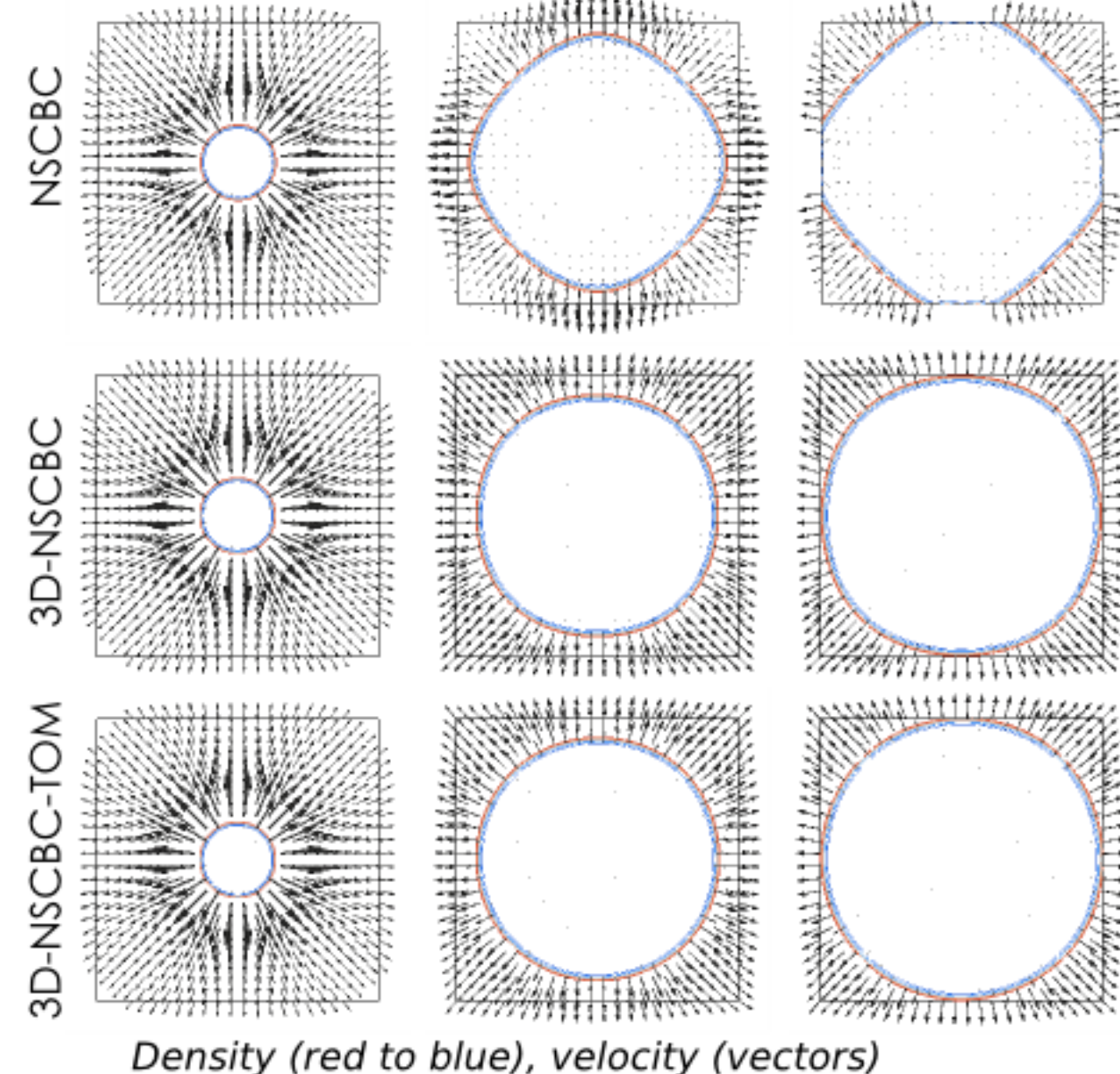


Vorticity (black iso-contours), density (gray gradients)

measure of maximum errors (parametric study) :

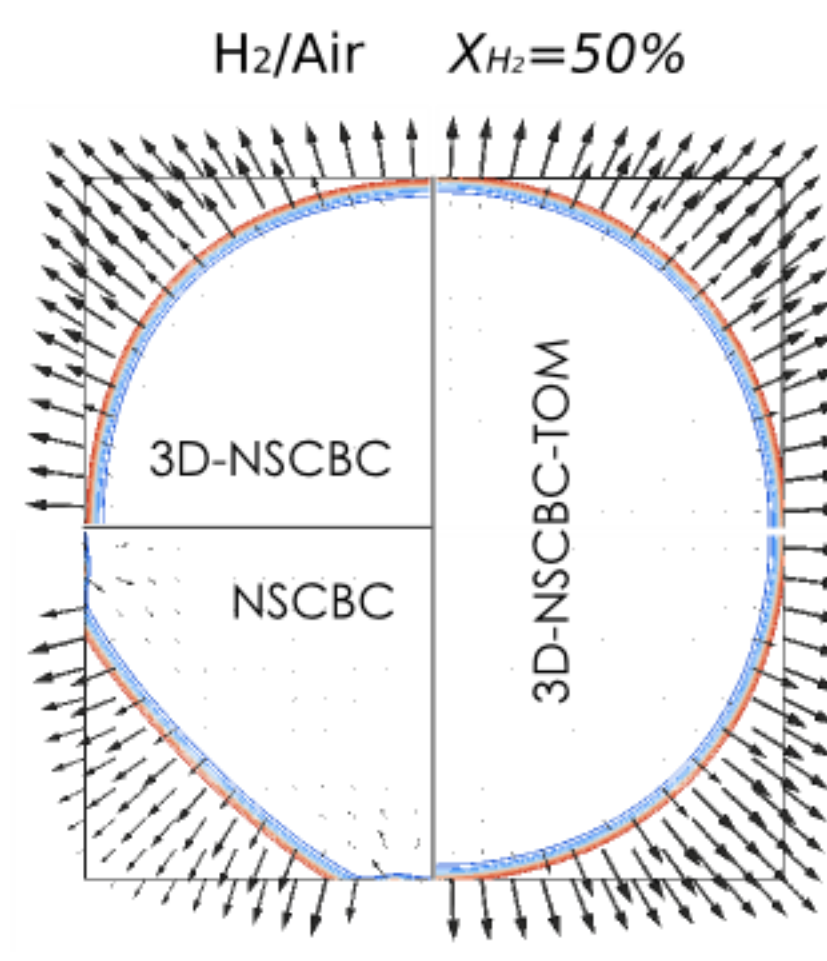


Flame ignition for 3 outflow treatments :



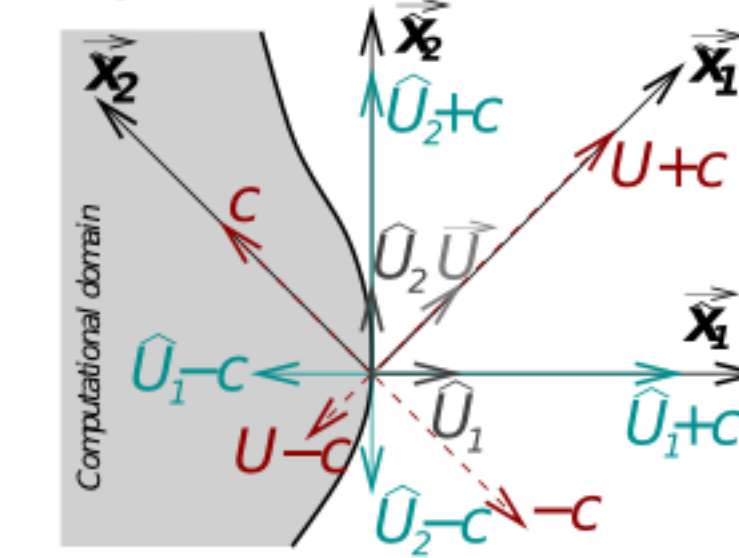
Density (red to blue), velocity (vectors)

3D-NSCBC-TOM decreases flow distortions when the mainstream is transverse.
(see vortex distortions, error curves and flame deformations)



3D-NSCBC-TOM strategy

Representation of characteristic velocities :



Modeling incoming acoustic terms is not frame independent.

$$\rho \left(\frac{\partial \tilde{U}_1}{\partial t} \tilde{x}_1 + \frac{\partial \tilde{U}_2}{\partial t} \tilde{x}_2 \right) = \rho \left(\frac{\partial \tilde{U}_1}{\partial t} \tilde{x}_1 + \frac{\partial \tilde{U}_2}{\partial t} \tilde{x}_2 \right)$$

NSCBC or 3D-NSCBC : characteristics decomposed on the normal of the outlet.

3D-NSCBC-TOM : characteristics decomposed on a local streamline based reference frame.

Conclusion

Current boundary conditions affect the accuracy of the solution.

The proposed 3D-NSCBC-TOM outflow treatment decreases flow distortions.

Simulations of expanding turbulent flames can lead to serious outflow instabilities.