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Luca Marioni, François Bay, Elie Hachem. Lid-driven cavity highly turbulent flow subjected to high magnetic field: Determination of critical time-step for explicit MHD schemes. 10th PAMIR International Conference Fundamental and Applied MHD, Jun 2016, Cagliari, Italy. 2016. hal-01311023

HAL Id: hal-01311023 https://hal.science/hal-01311023

Submitted on 3 May 2016

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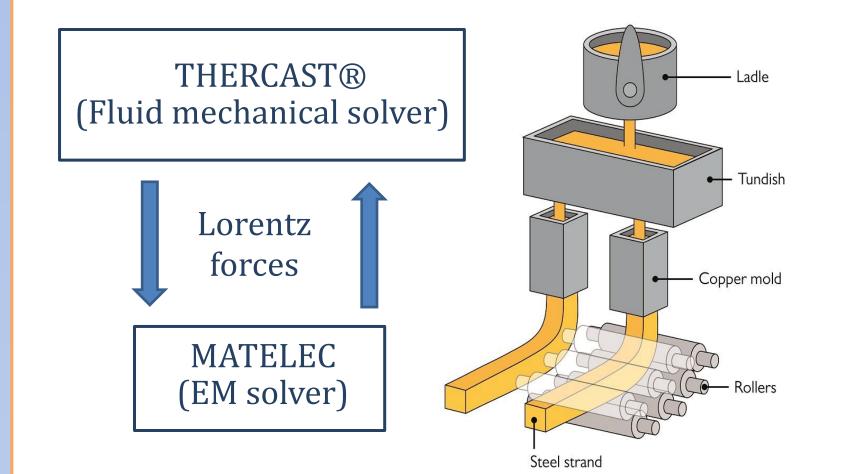




Lid-driven cavity highly turbulent flow subjected to high magnetic field Determination of critical time-step for explicit MHD schemes

Control of fluid flow in CC:

- > Electromagnetic **braking** and **stirring** in **continuous casting** process of steel
- Coupled simulation in commercial software:

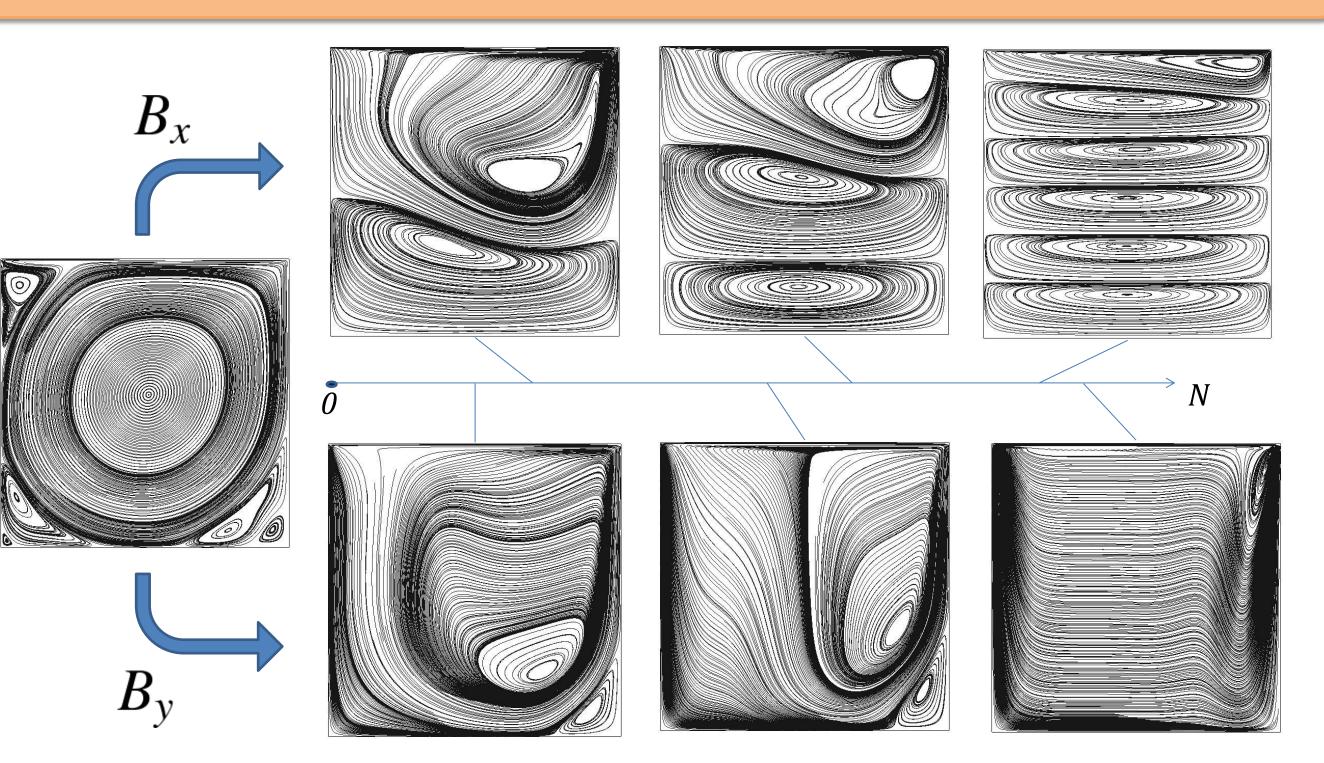


A representative study case:

- ➢ Problem:
 - Highly **turbulent flow**

> Solution:

- Impose a constant magnetic field to control and **brake** the flow
- > Numerical procedure:



- Lid-driven cavity benchmark^[1]
- Relate the **Stuart number** (N) to the target braking level

Computational model:

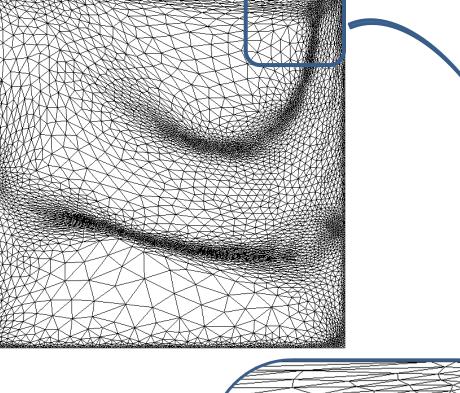
Numerical instabilities:

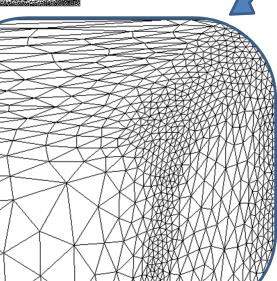
Electromagnetic Field: $\Delta \phi = \partial_z (u_x B_y - u_y B_x) \equiv 0$

Lorentz Forces: $f_L = \boldsymbol{\sigma}(\boldsymbol{u} \times \boldsymbol{B}) \times \boldsymbol{B}$

Navier-Stokes: (multiscale stabilized FE^[2]) $\begin{cases} \rho(\partial u + u \cdot \nabla u) - \nabla \cdot (2\mu\varepsilon(u) - p\mathbb{I}) = f_L \\ \nabla \cdot u = 0 \end{cases}$

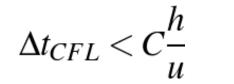
Anisotropic mesh adaptation[3].

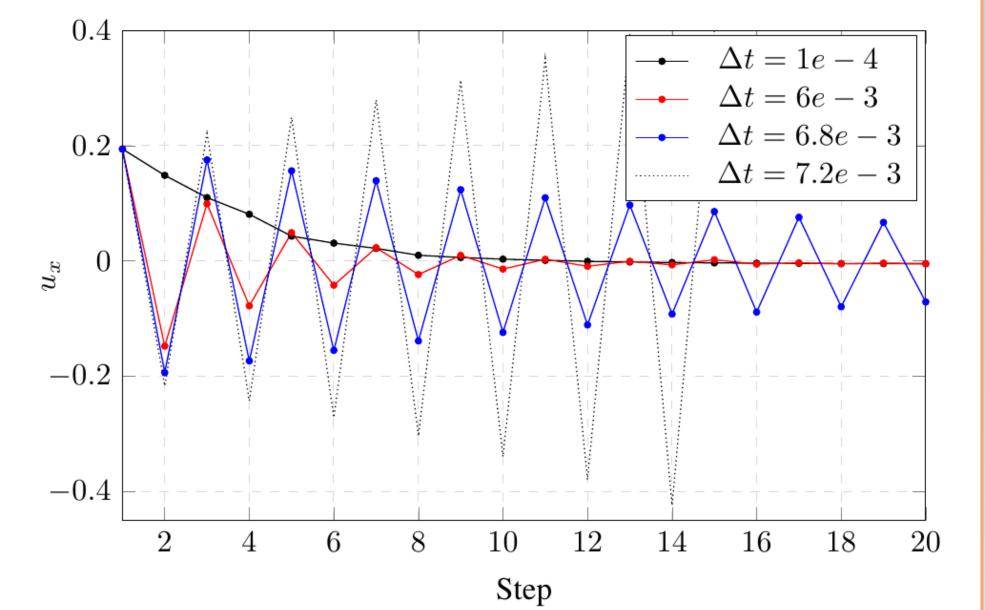




The Lorentz force is tracked explicitly.

- The excessive size of the timestep leads to completely brake the flow normally to *B* and to accelerate it in the opposite direction, i.e. $u^n \cdot f_L^n < 0$.
- The CFL condition is not capable anymore to guarantee numerical convergence.

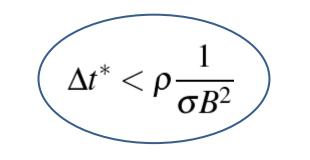


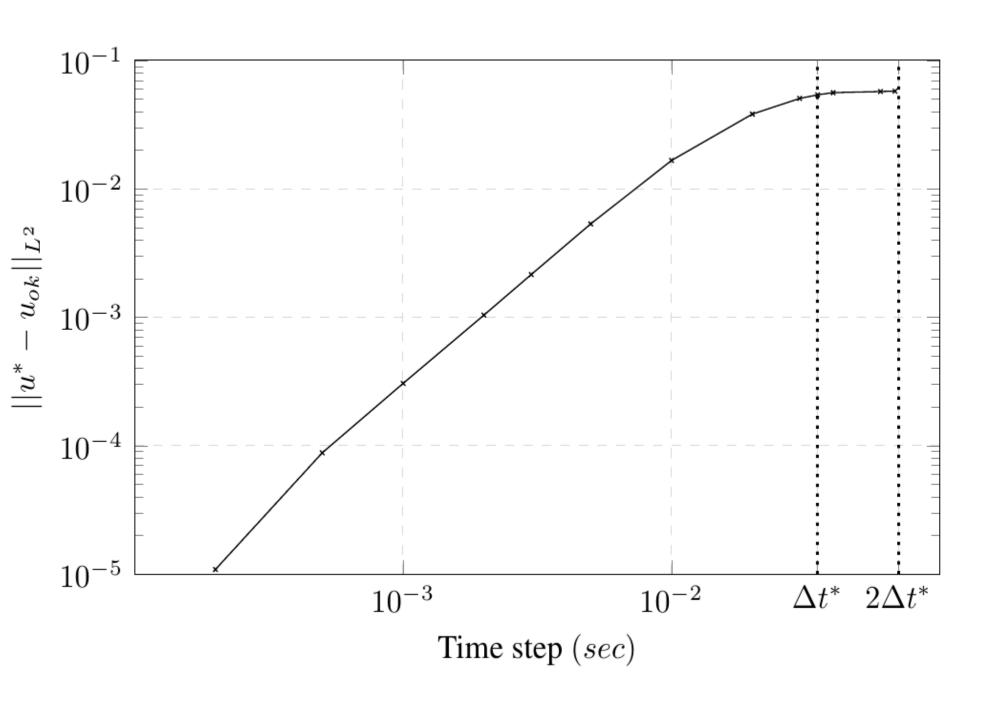


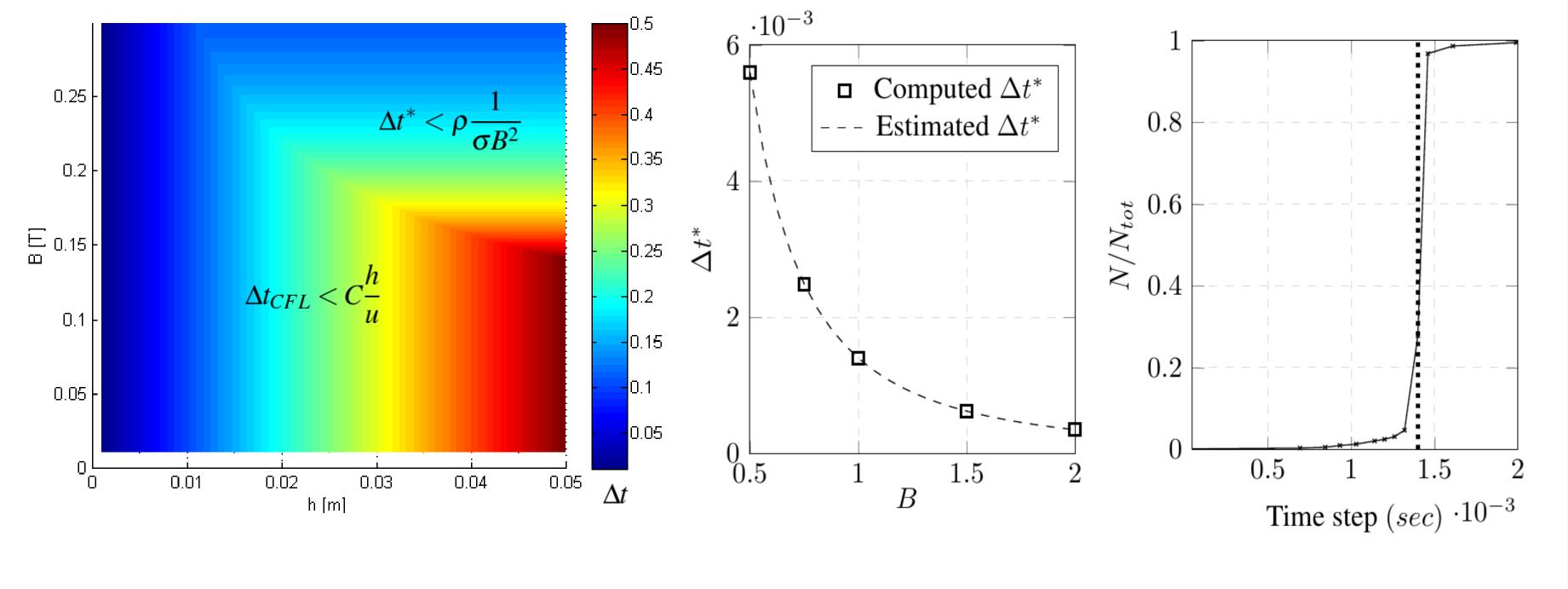
Determination of the critical time-step:

> Solution:

Computation of the **limit** time-step as the time-step which leads to a complete dissipation of the kinetic energy within one time increment when the magnetic field is normal to the velocity.







Conclusions & Perspectives:

> The flow is highly affected by the magnetic field and its direction.

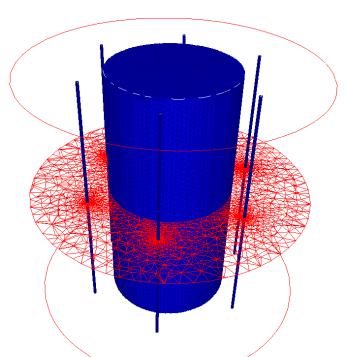
≻In some configurations, the CFL condition is not enough to guarantee the numerical convergence.

>A new **time-step threshold** which guarantees convergence in explicit schemes is proposed.

>An **implicit** modelling of the Lorentz force has to be included in the multiscale stabilized finite-elements solver.

The braking effect will be taken into account in the complete simulation of electromagnetic stirring.





Acknowledgements:

The authors would like to gratefully thank Transvalor for funding this research and for the continuous support which allowed the full exploitation of its software's capabilities.

References:

[1] U. Ghia, K. N. Ghia, and C. Shin. High-resolution for incompressible flow using the Navier-Stokes equations and a multigrid method. Journal of computational physics, 48(3):387–411, 1982.

[2] E. Hachem, B. Rivaux, T. Kloczko, H. Digonnet, and T. Coupez. Stabilized finite element method for incompressible flows with high Reynolds number. Journal of computational physics, 229:8643-8665, 2010.

[3] T. Coupez and E. Hachem. Solution of high-Reynolds incompressible flow with stabilized finite element and adaptive anisotropic meshing. Computer Methods in Applied Mechanics and Engineering, 267:65–85, 2013.

