Development of a 3D Hybridized Discontinuous Galerkin Solver For Inductively Coupled Plasma

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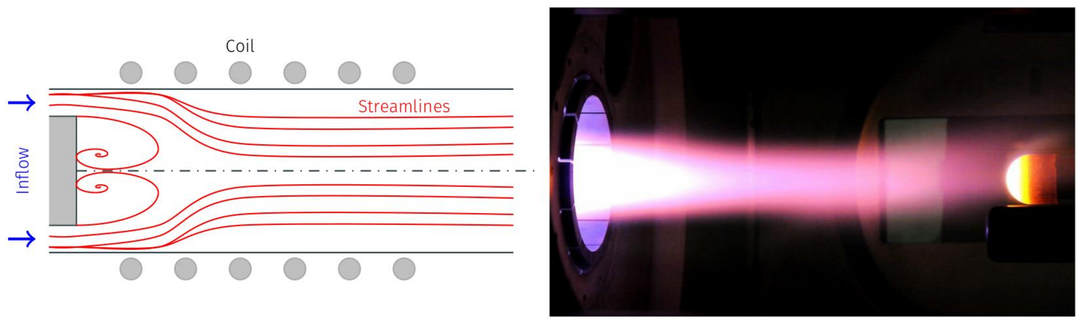
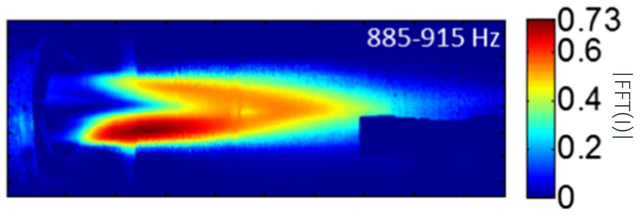
Introduction

Plasmatron: World's most powerful ICP facility.

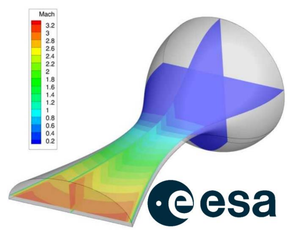


ICP simulation ease experimentations: **need performant solvers.**

Main Challenges: Unsteady and 3D phenomena



Ripple part of the current rectifier fully transmitted: **impact on experiments**!



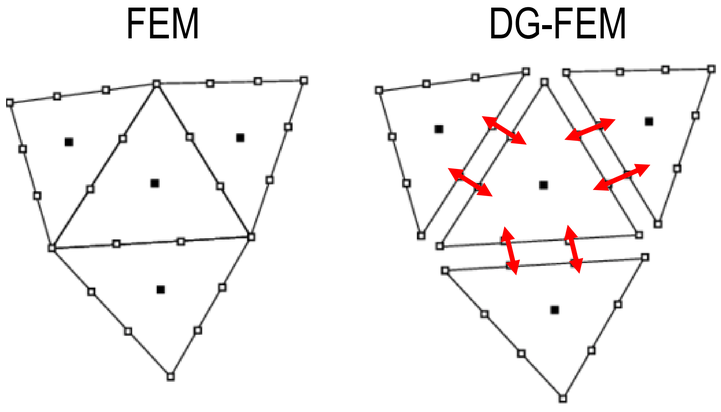
Simulation of **non-axisymmetric nozzles** or **3D plasma modes**.

Finite volume solutions exist (**COOLFluiD**), but they are **not 3D nor time-accurate**. [1]

COOLFLUID

Methods

The Discontinuous Galerkin method



The Discontinuous Galerkin method is a **high-order numerical scheme** for solving PDE. It is similar to FEM in the sense that it **represents the solution with a functional basis**, but it transfer information using **numerical fluxes** such as FV. A flavor of DG, called **HDG** is used here.

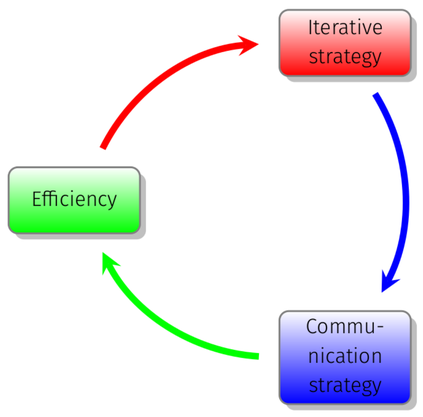
Chemistry: Mutation++

Mutation++ [2] is a library that computes the thermodynamic properties of **ideal gases**.
It outputs equilibrium and non-equilibrium data. For the present work, only **equilibrium** is considered.

Mutation++
Multicomponent Thermodynamic And Transport properties for IONized gases in C++

$$\mathrm{C} + \mathrm{O} \leftrightarrows \mathrm{CO}^+ + \mathrm{e}^-$$
$$\mathrm{O} + \mathrm{O} \leftrightarrows \mathrm{O}_2^+ + \mathrm{e}^-.$$

Parallelization



Since the problem is 3D, a **parallelization strategy must be devised**. The details of the strategy have yet to be determined, but it will be a mix between **shared** and **distributed** memory.

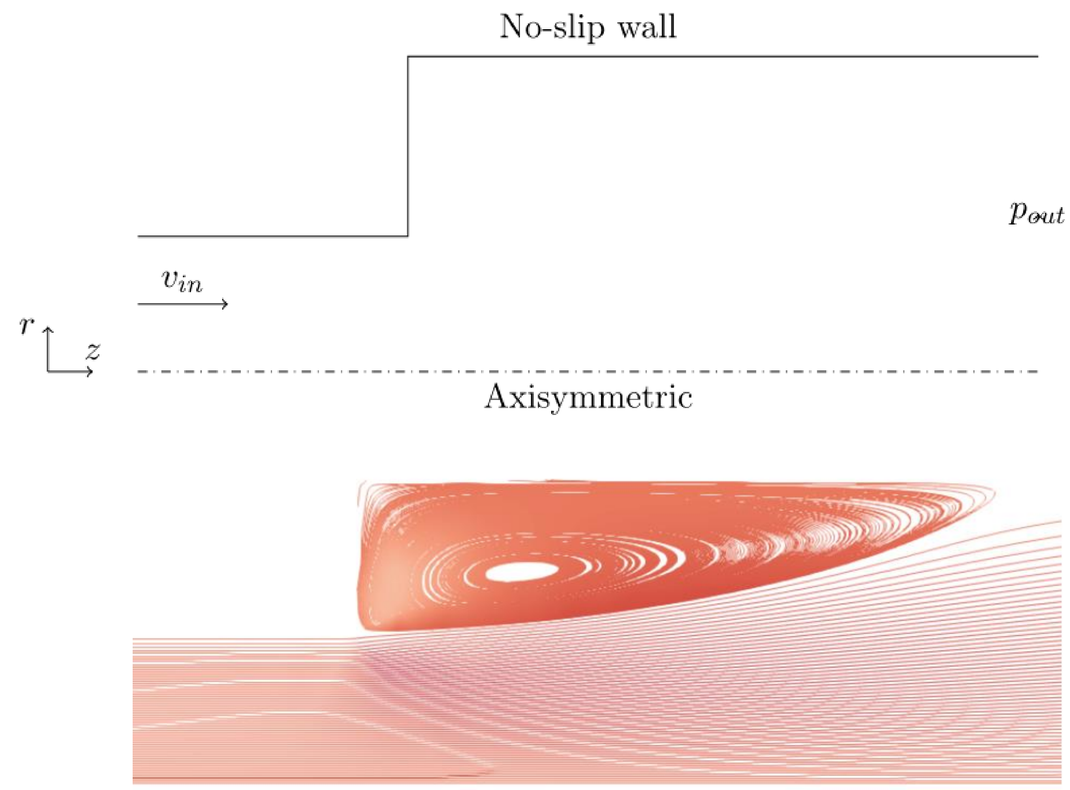
OpenMP

Open MPI

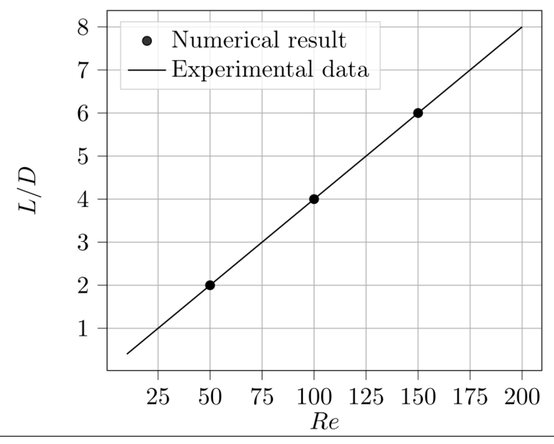
Results [3]

Axisymmetric configuration

First step of the solver design is the **axisymmetric configuration**.

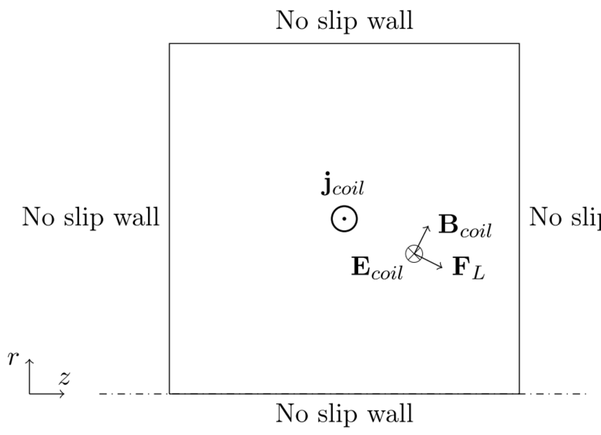


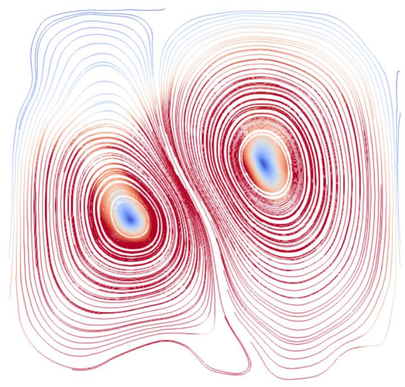
The recirculation length is supposed to be a linear function of the Reynolds number in the range $50 < Re < 200$. This behaviour can be observed in our numerical simulations.



Magnetohydrodynamic equations

Plasma flows are governed by the MHD equations. Vortices start to form under the Lorentz force produced by an immersed coil.





What's next?

- The thermodynamic modelling must be verified.
- A case of a high-enthalpy jet is under verification. Once the solver is verified, a validation case with COOLFluiD will be set-up and compared to the MHD solver.

References

[1] A. Lani, N. Villedieu, K. Bensassi, L. Kapa, M. Vymazal, M. S. Yalim, and M. Panesi. COOLFluiD: An open computational platform for multi-physics sim- ulation and research. 21st AIAA Computational Fluid Dynamics Conference, (May 2014), 2013.

[2] James B. Scoggins, Vincent Leroy, Georgios Bellas-Chatzigeorgis, Bruno Dias, and Thierry E. Magin. Mutation++: MUlticomponent Thermodynamic And Transport properties for IONized gases in C++. SoftwareX, 12, 2020.

[3] Corthouts, Nicolas. 2021. Development of an Axisymmetric Hybridized Discontinuous Galerkin Solver for Inductively Coupled Plasma. Rhode-Saint-Genèse, Belgium.

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