RANS computations of a quasi-axial flow in an in-line tube bundle

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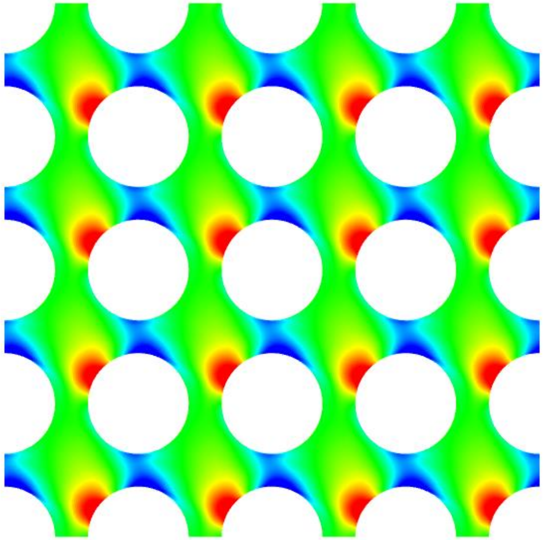


CHANGER L'ÉNERGIE ENSEMBLE

Outlook

- Context
- Objectives and strategy
- Configuration
- Results
- Conclusion and perspectives

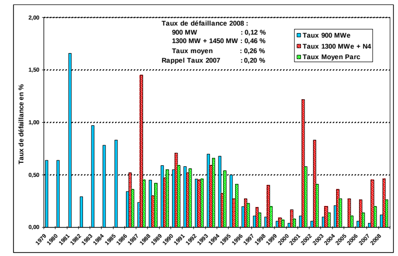
Context

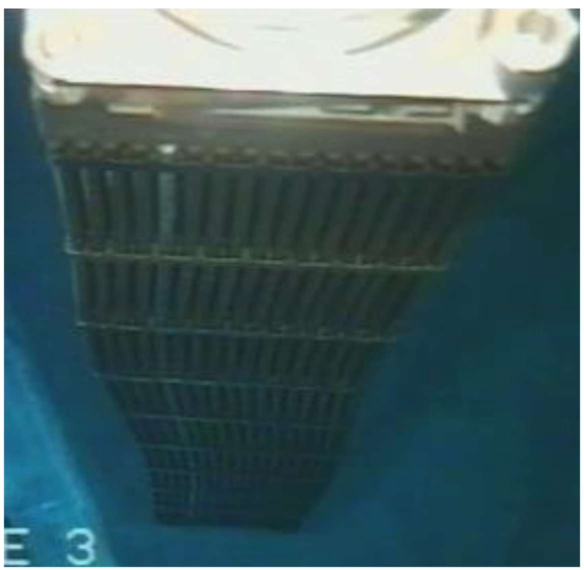
Context / Fuel assemblies issues

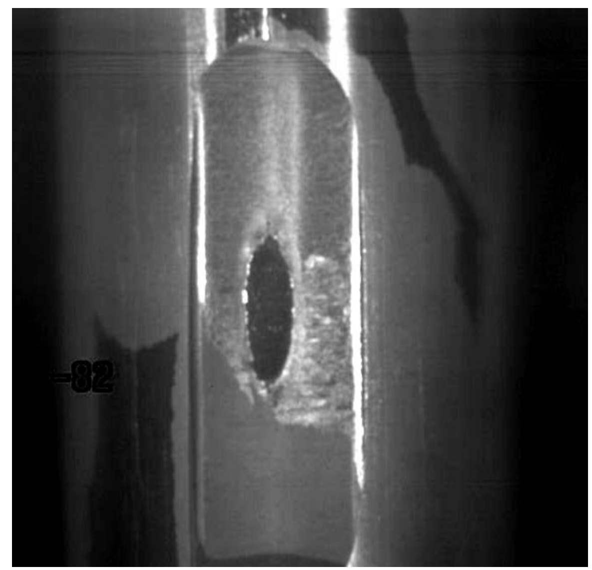
❑ Reliability and performance of Fuel assemblies in the core

- **25** days of non-availability due to problems concerning the fuel assemblies (2008)

2 major issues







Deformations (RANS)

Fretting, vibrations (LES)

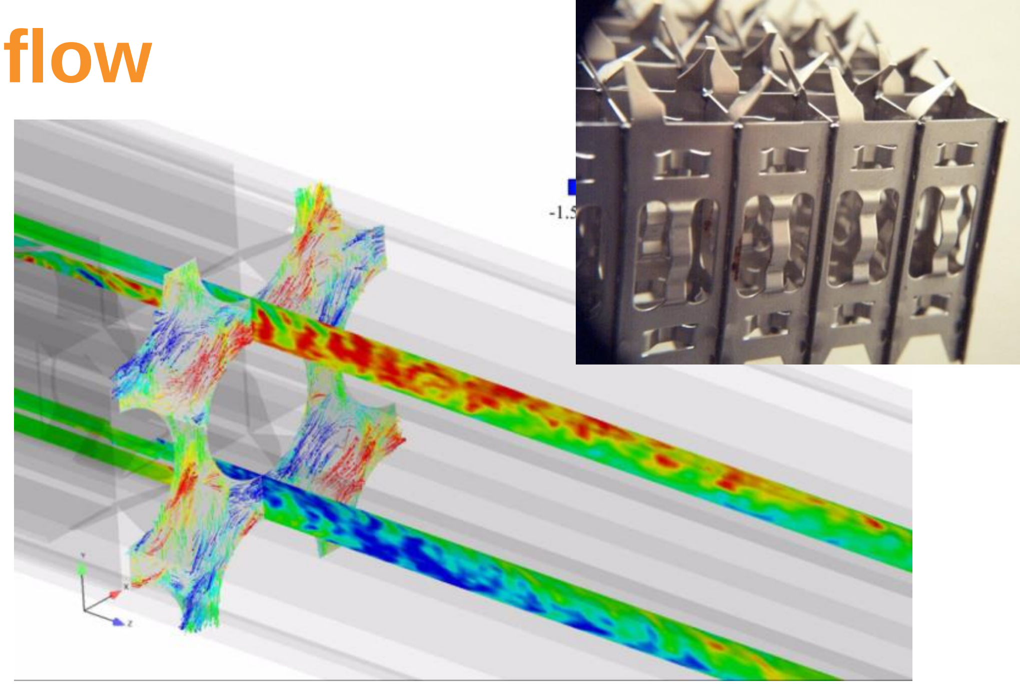
Context / strong cross-flow

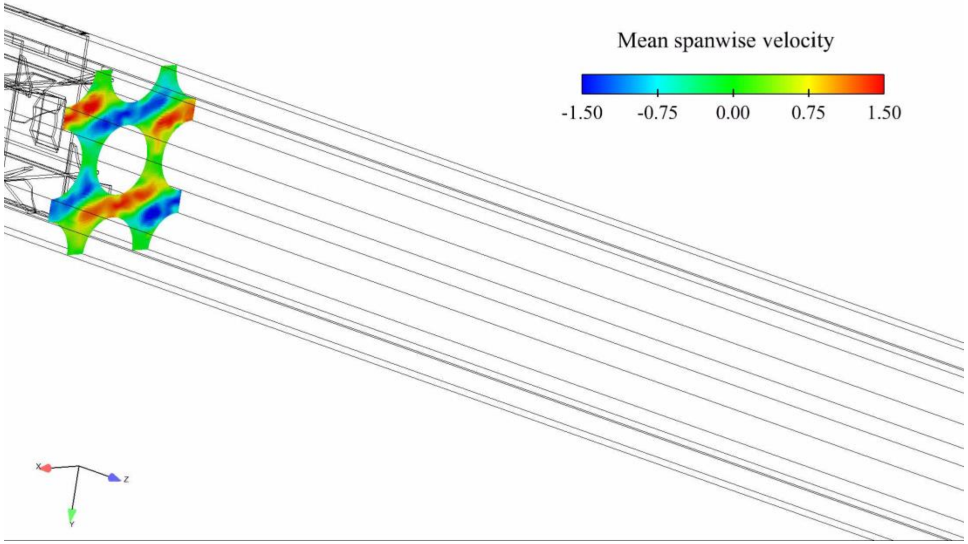
❑ Transverse velocity component downtream a typical mixing grid (previous LES computations on a 2x2 fuel assembly with periodic boundary conditions)

❑ Very high local values, up to 50% of the stream-wise bulk velocity in the narrower region

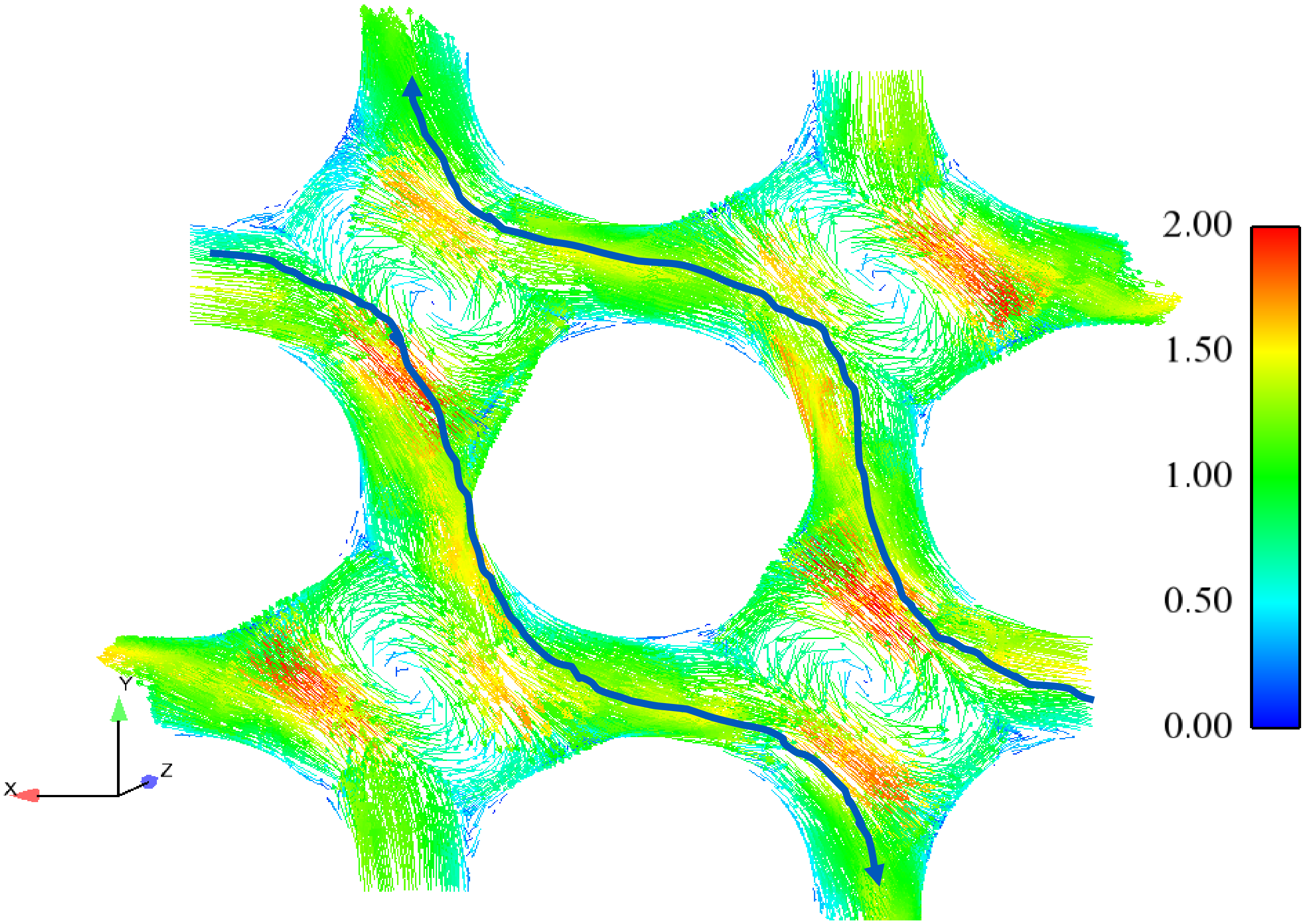
❑ Thus, inclined flows in the bare bundle

❑ Almost, nothing in the littérature for quasi axial-flows in bare bundles (in particular for pressure drop coefficients, exp. Difficult/impossible to carry out)





Context / strong cross-flow



Objectives and strategy

Objectives / Strategy

- General objective: understanding the dynamics of the quasi-axial flow through square tube bundles

- Need of pressure drop coefficient to be used in coarser approaches (such as the ones used in THYC or CATHARE to simulation the whole core of a vessel)

- Actual objective: Prediction of pressure drop coefficients for quasi-axial flows in a typical PWR fuel assembly tube bundle.

- Long term strategy:
  - Validation of RANS for pure axial flow coefficients at different Reynolds numbers against available experimental data
  - Validation of a Reynolds Averaged Navier-Stokes (RANS) approach for few quasi-axial flows computed with Large Eddy Simulation (LES) at a given Reynolds number (no exp. available to the authors' knowledge)
  - Performing parametric RANS studies in order to extract correlations

Objectives / Strategy

❑ Strategy for RANS approaches :

➢ **Mesh** sensitivity study

➢ Study of the sensitivity to **the dimension of the bundle (tubes number)**

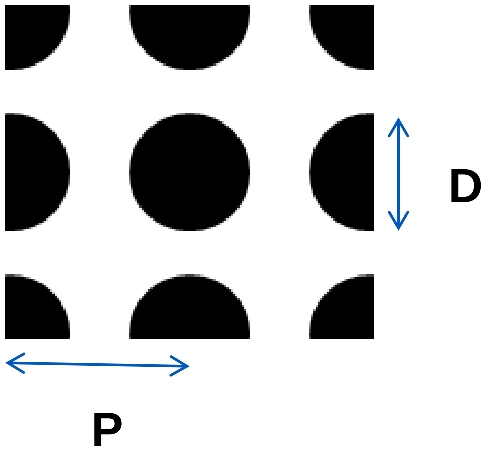
➢ Sensitivity to the **turbulence model**

=> Leads to **one** choice at the end to perform parametric studies

Configuration

Configuration / Typical computation

- RANS modeling
- Tri-periodic boundary conditions
- One imposes the pressure loss in the three directions

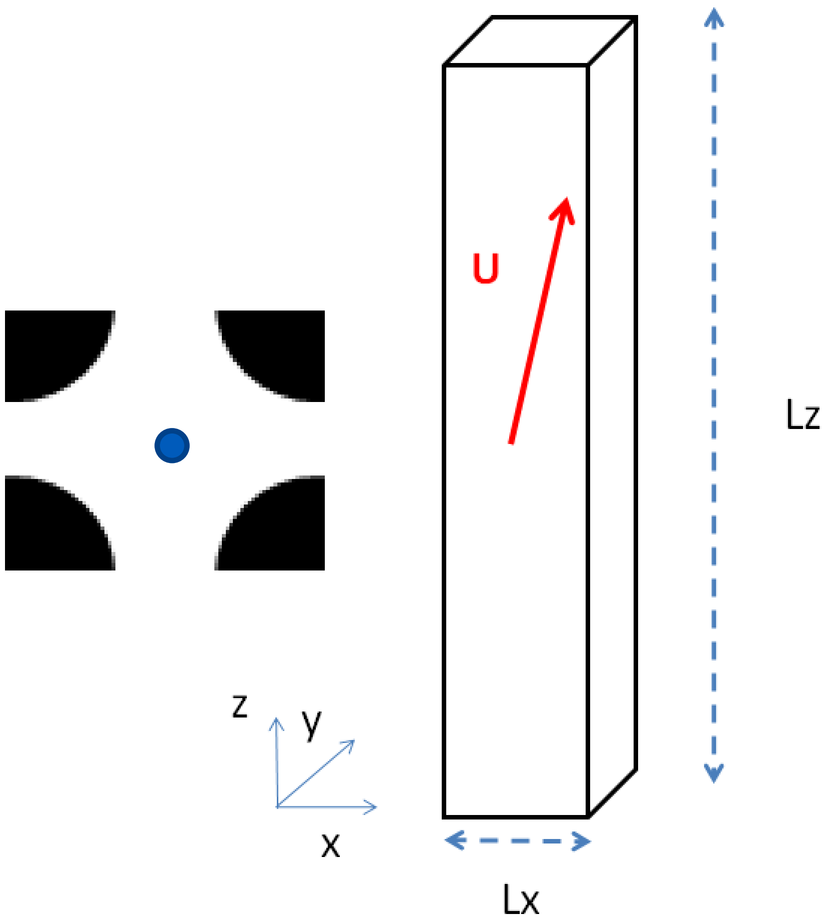


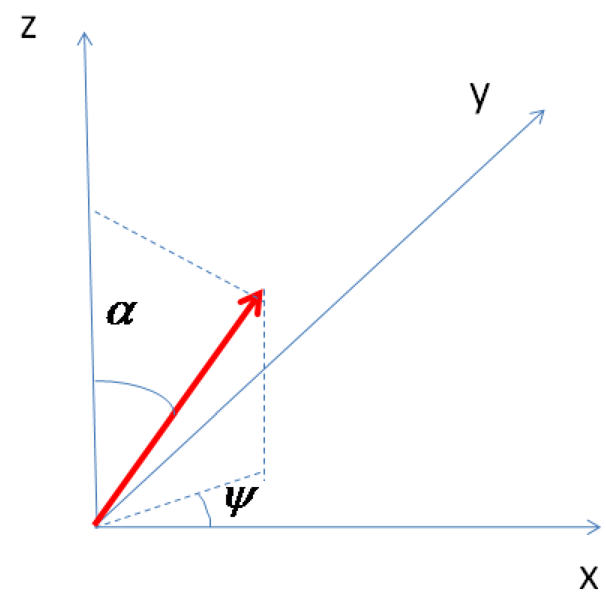
$$\frac{\partial \overline{u_i}}{\partial t} + \frac{\partial \left(\overline{u_i}\,\overline{u_j}\right)}{\partial x_j} = -\frac{1}{\rho_0}\frac{\partial \overline{p}}{\partial x_i} + \nu \frac{\partial^2 \overline{u_i}}{\partial x_j \partial x_j} - \frac{\partial \overline{u'_i u'_j}}{\partial x_j} + \boxed{S_i}$$

$$\frac{\partial \overline{u_j}}{\partial x_j} = 0$$

- The axial Reynolds number is always close to 50000 and a pitch to diameter ratio **P/D=1.326**
- 2D meshes (only one cell in the z direction) with hexadral conforming cells
- Mesh created with Salomé

Configuration / Quasi-axial flows in tube bundles





$$\mathrm{Re}_H = \frac{U D_H}{\nu}, \quad \xi_\mathrm{i} = \frac{2 S_i D_H}{\rho U_i^2}$$

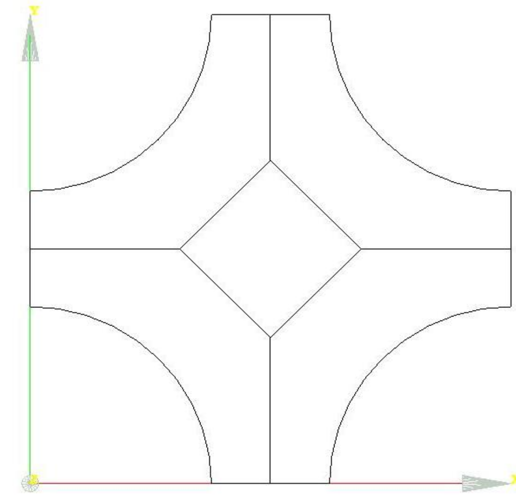
Mesh generation

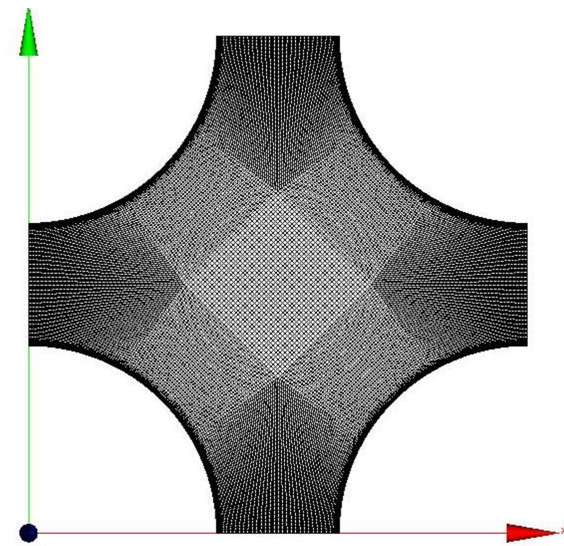
❑Strategy :

➢ Creation of the geometry with the ***GEOM*** module

➢Meshing with the ***SMESH*** module

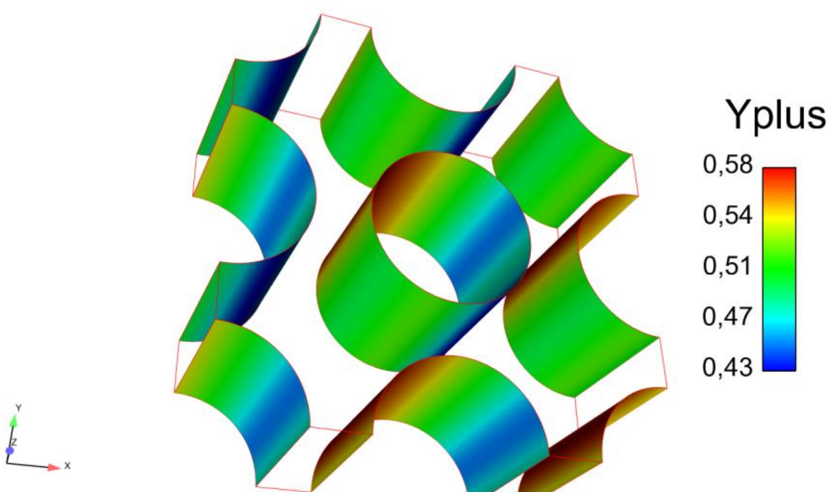
➢ Use of the ***dump study*** function to create a Python file





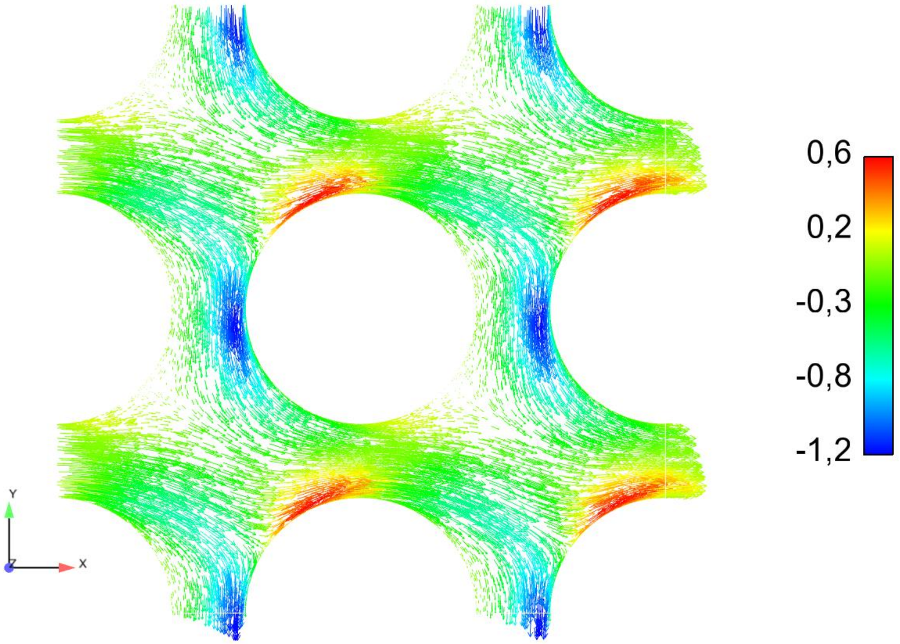
❑ Advantages :

➢ The mesh and the geometry are **fully customizable** and easy to re-create

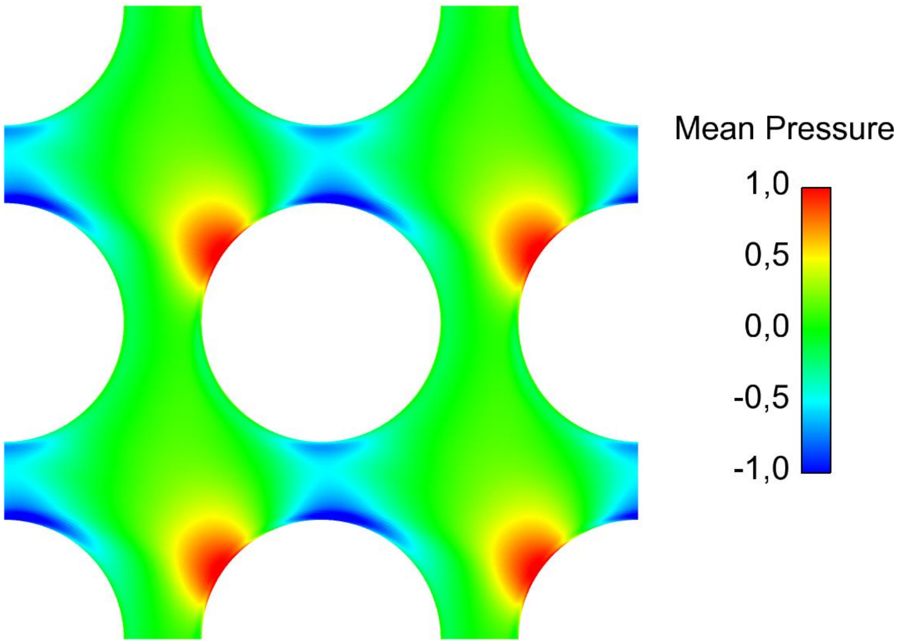


Results

Results / Major issue (asymmetry)



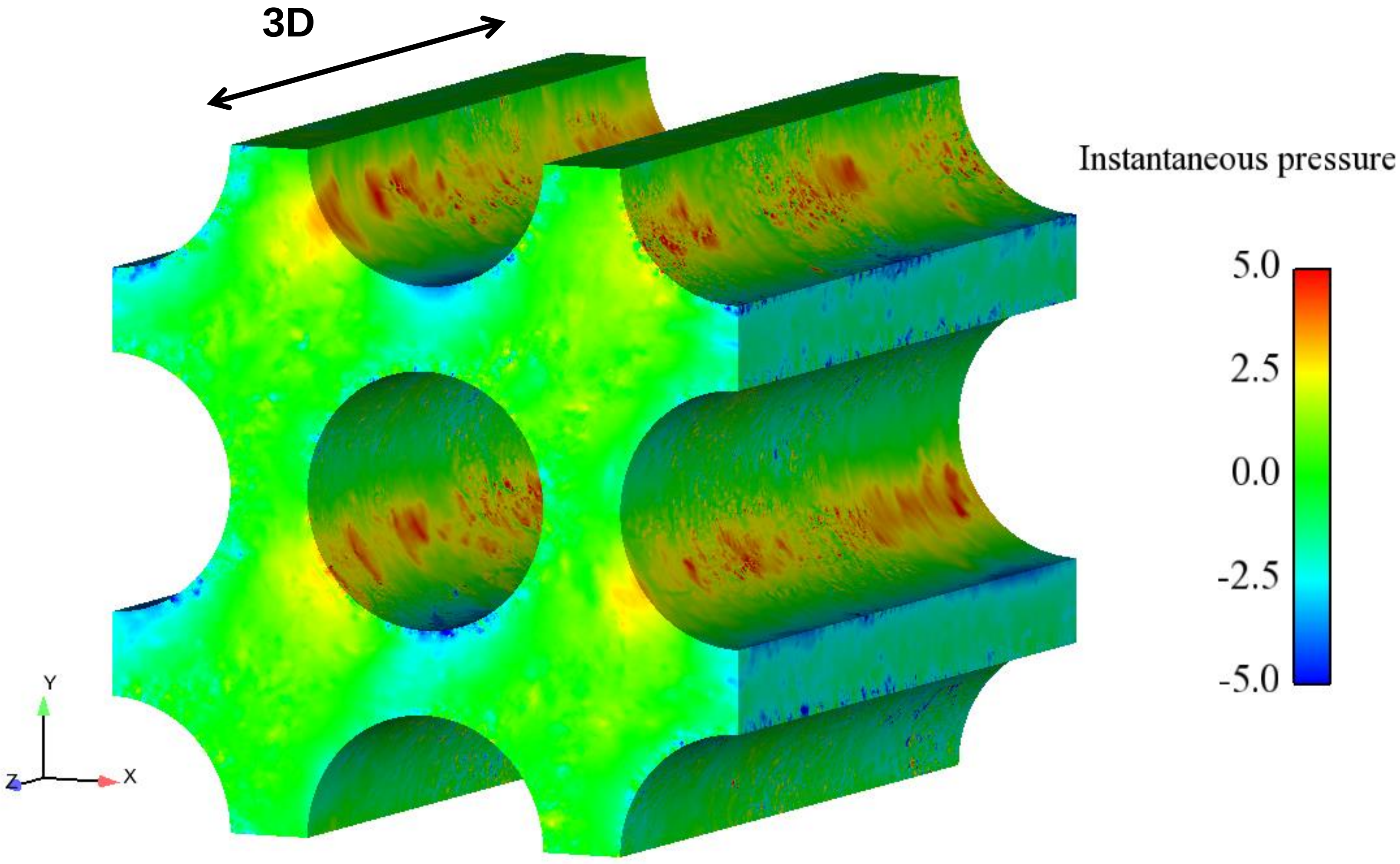
Mean transverse velocity vector coloured by the mean transverse velocity in y direction, 2x2 , Su=0,5, Sv=0, Sw=1



Mean presure, 2x2 , Su=0,5, Sv=0, Sw=1

- Considering the symmetry of the configuration, one should *a priori* have $\psi=0$ and $\alpha=?$
- One obtains here $\psi=23°$ and $\alpha=2°$
- This asymmetry is observed in the very first LES computations

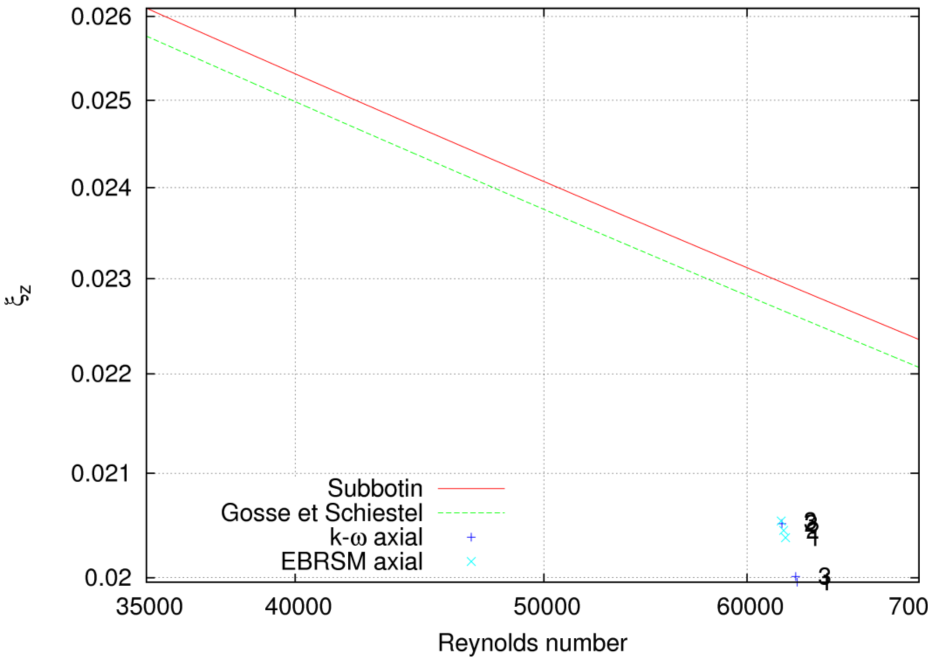
Results / Major issue (asymmetry)



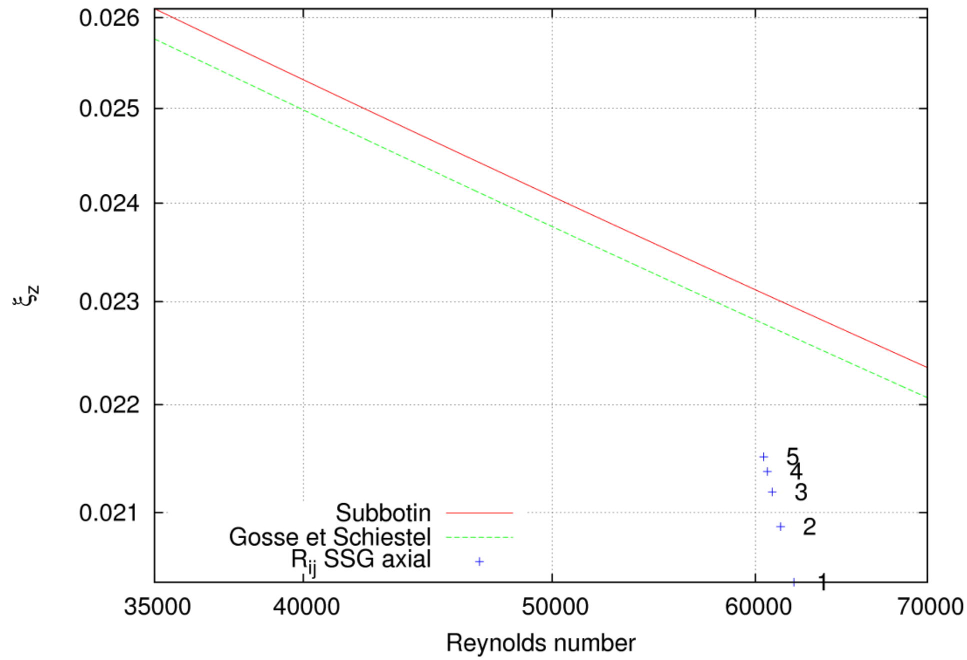
Instantaneous presure field with LES (100 M cells), 2x2 , Su=1, Sv=0, Sw=1

Results / Mesh Sensivity

- 2x2 tube bundle, P/D=1.326
- Different mesh raffinements
- Sw=1, Sv=0, Re~62,000
- Axial pressure loss coefficient



Low Reynolds Number models



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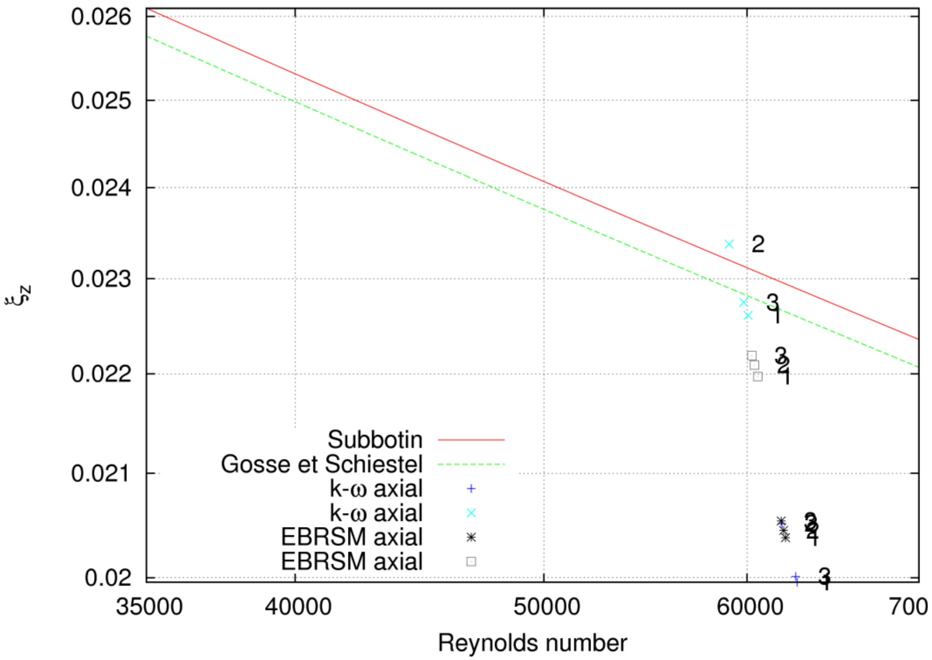

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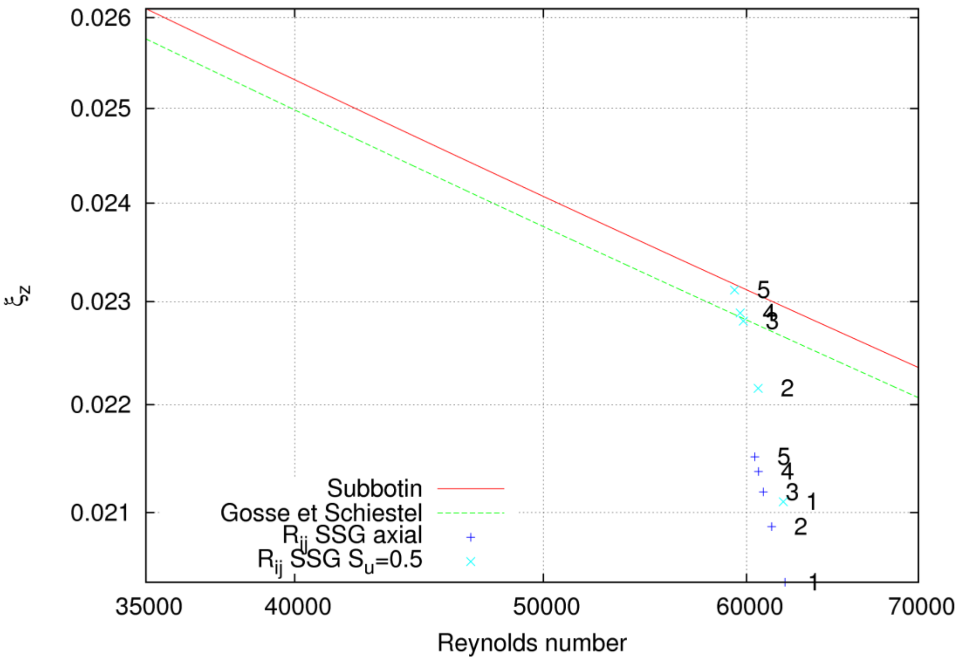

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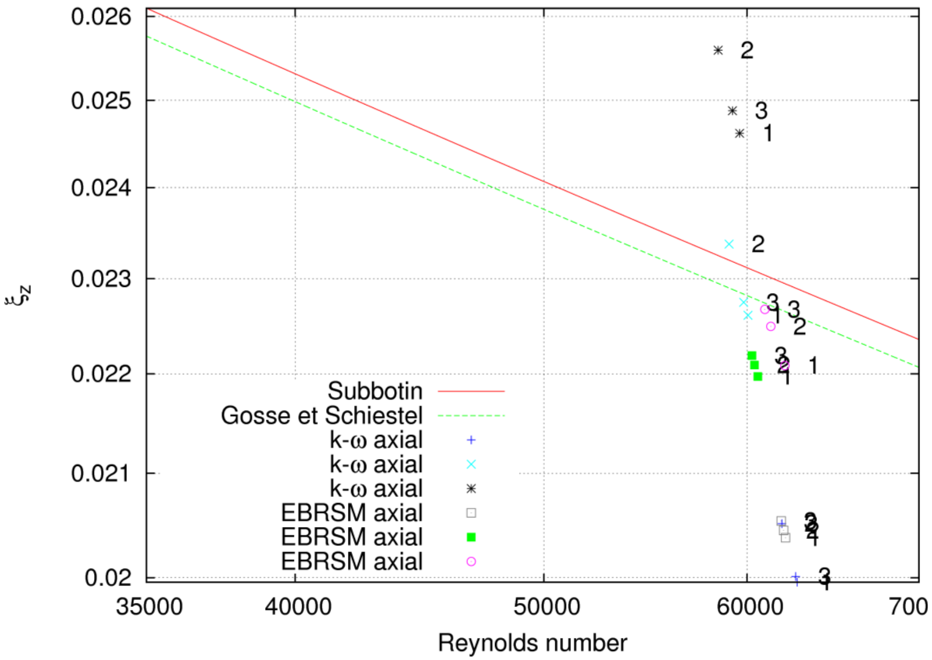

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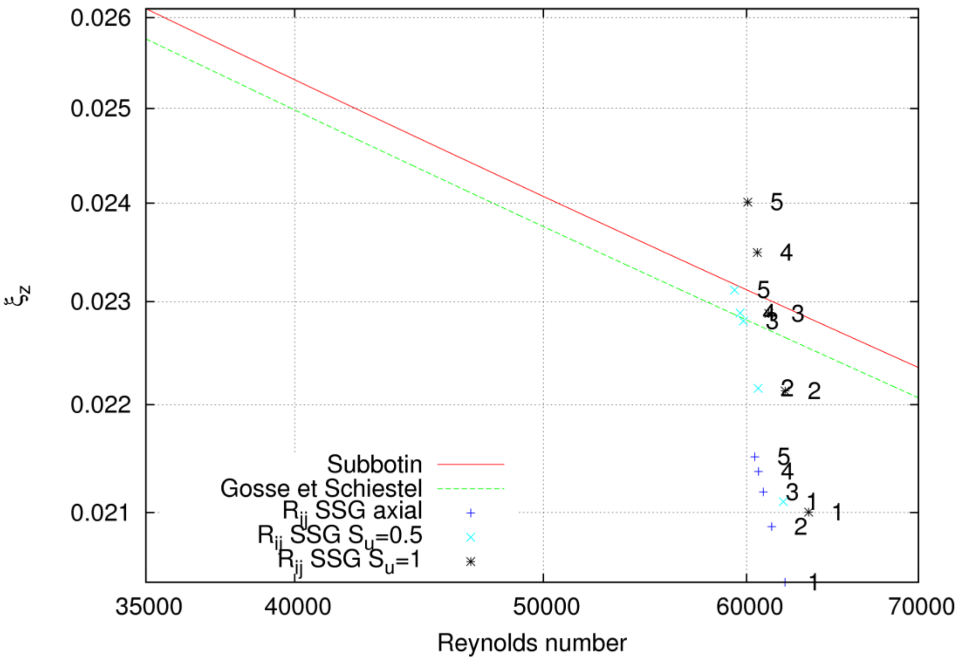
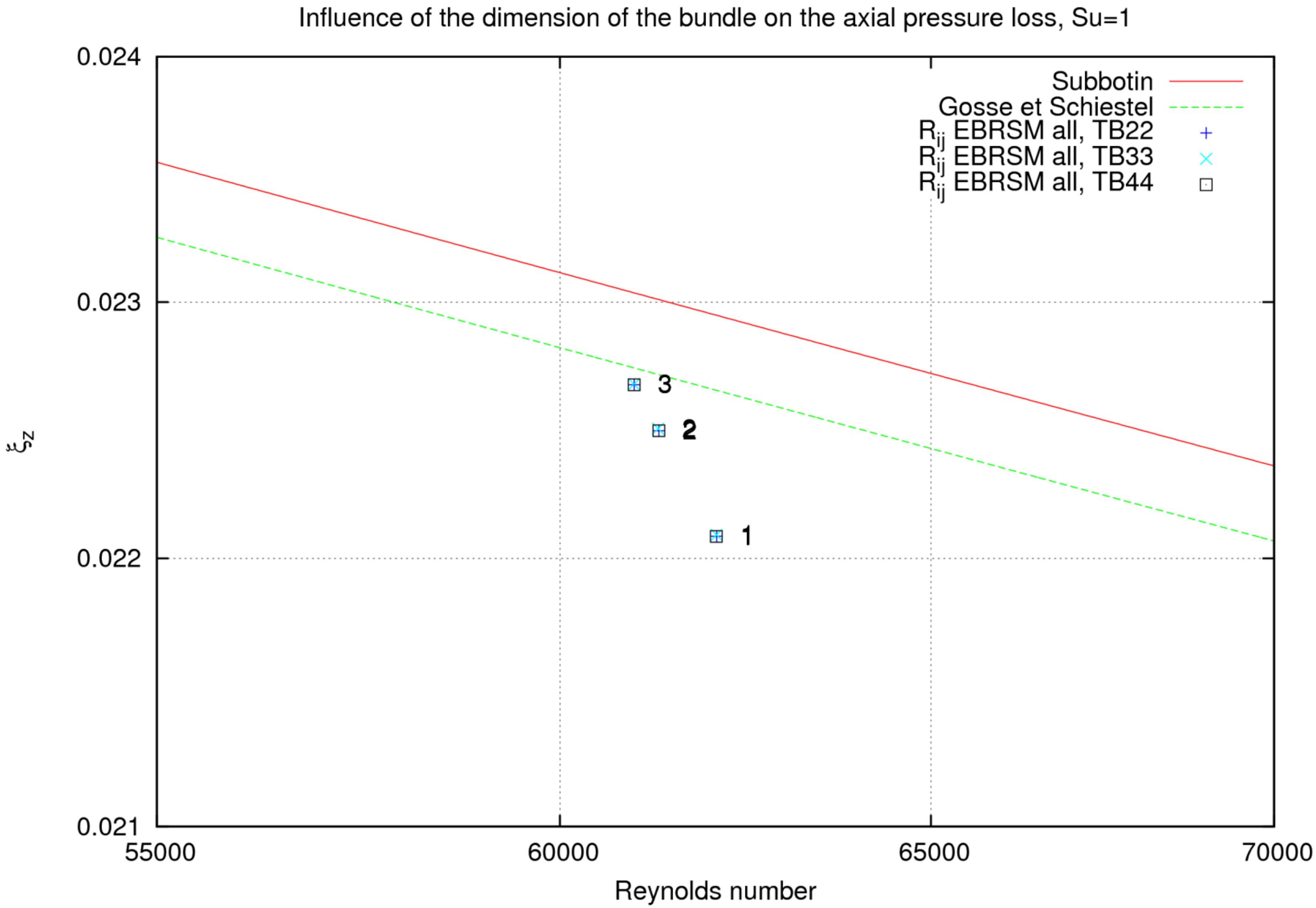


High Reynolds Number models

Results / Sensivity to the bundle size



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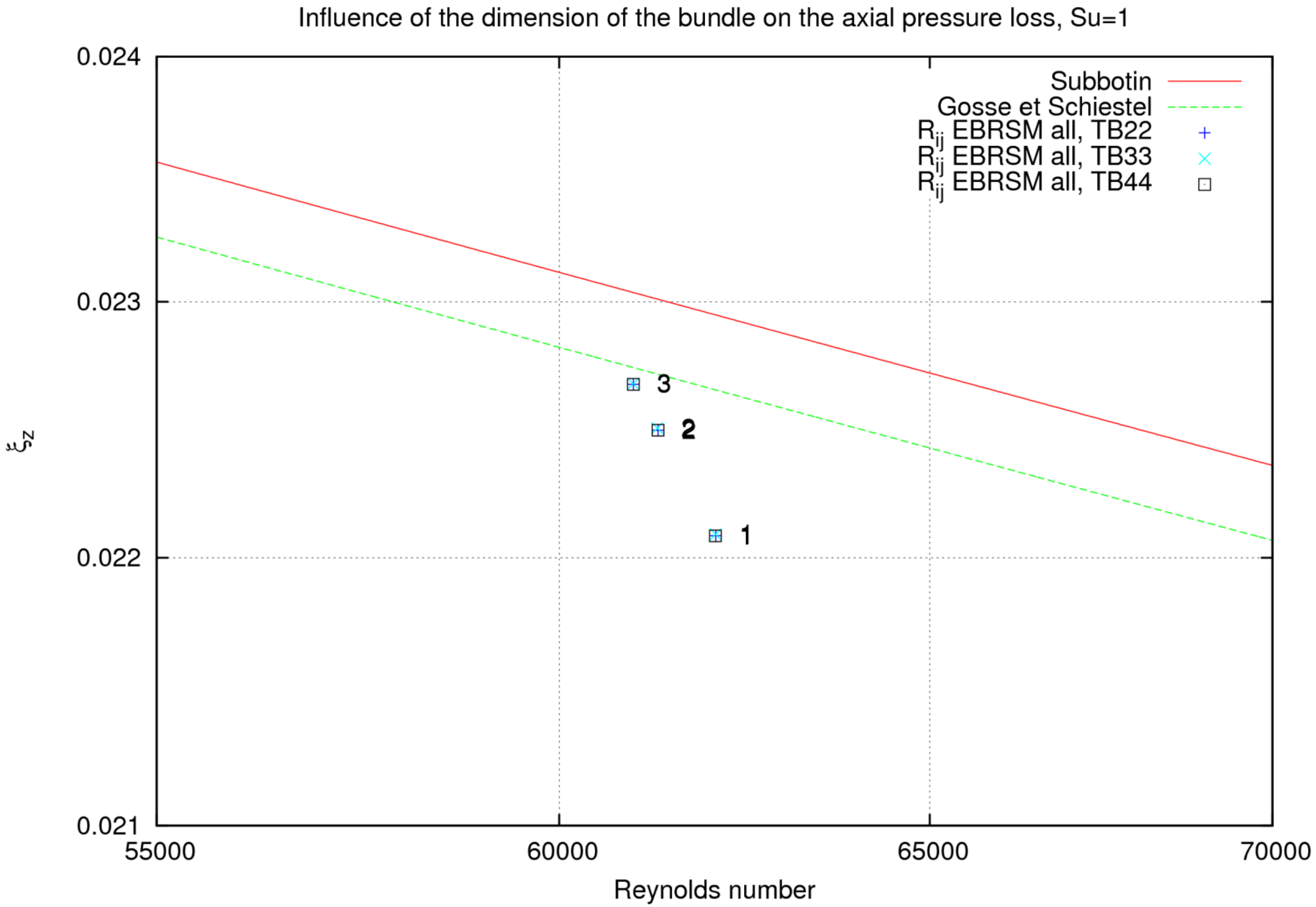
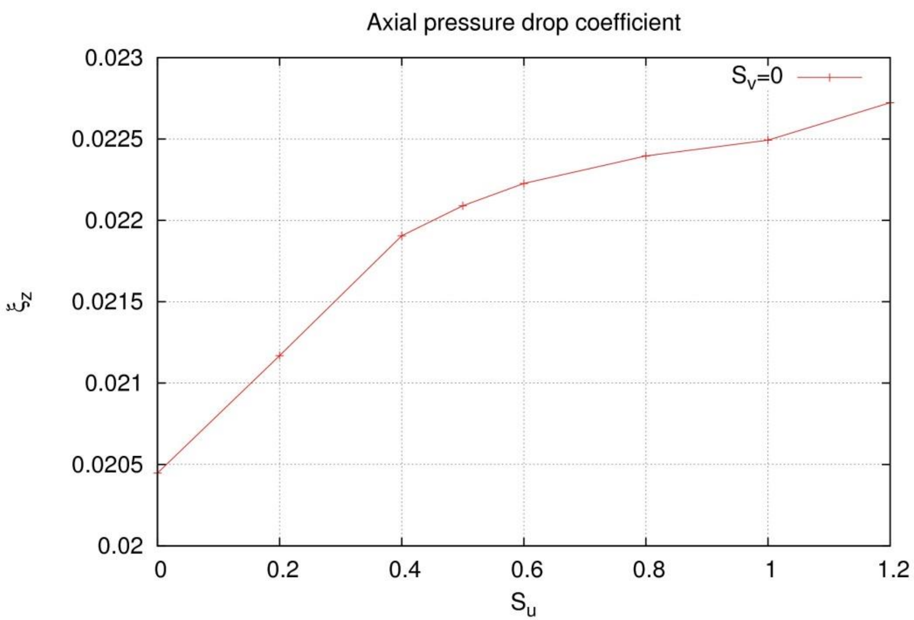
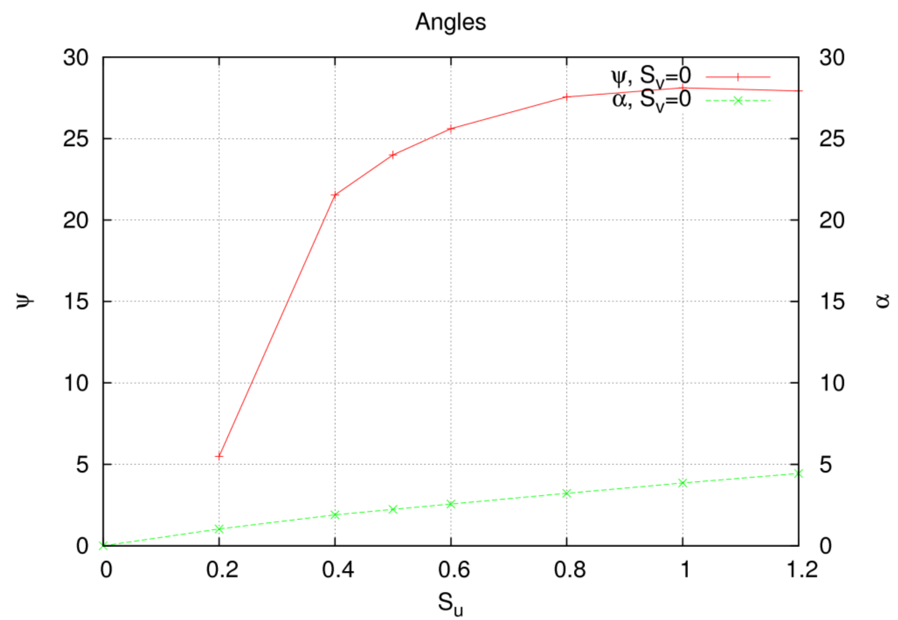


Results / Variation of the S_u source term

- ❑ 2x2 tube bundle, P/D=1.326
- ❑ Sw=1, Sv=0, Re~62,000
- ❑ Axial pressure loss coefficient and angles of the configuration



Axial pressure loss coefficient



Angles of the configuration

- ➢ The authors start to think that this configuration is physically impossible!

Results / Variation of the S_u source term

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- Sw=1, Sv=1, Re~62,000
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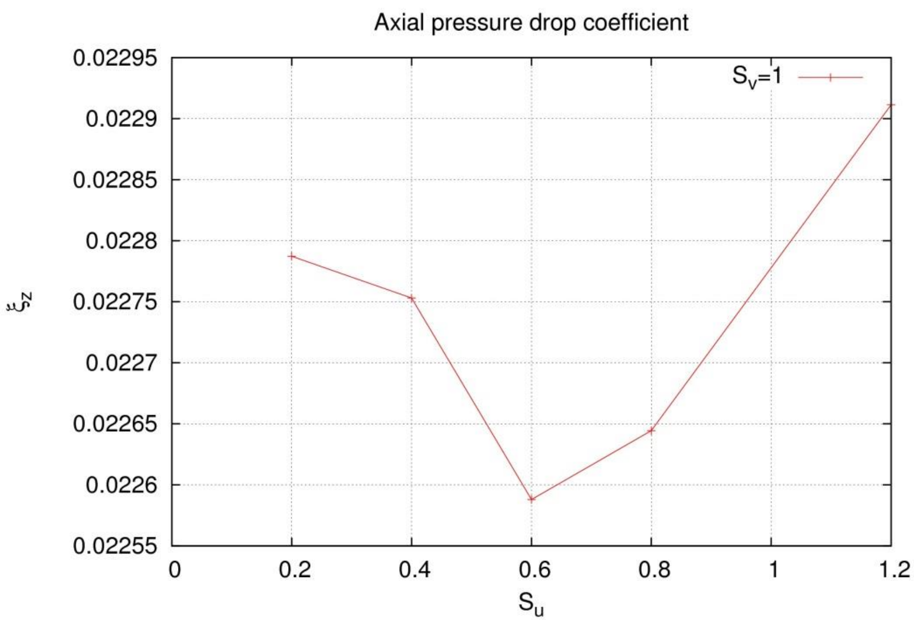
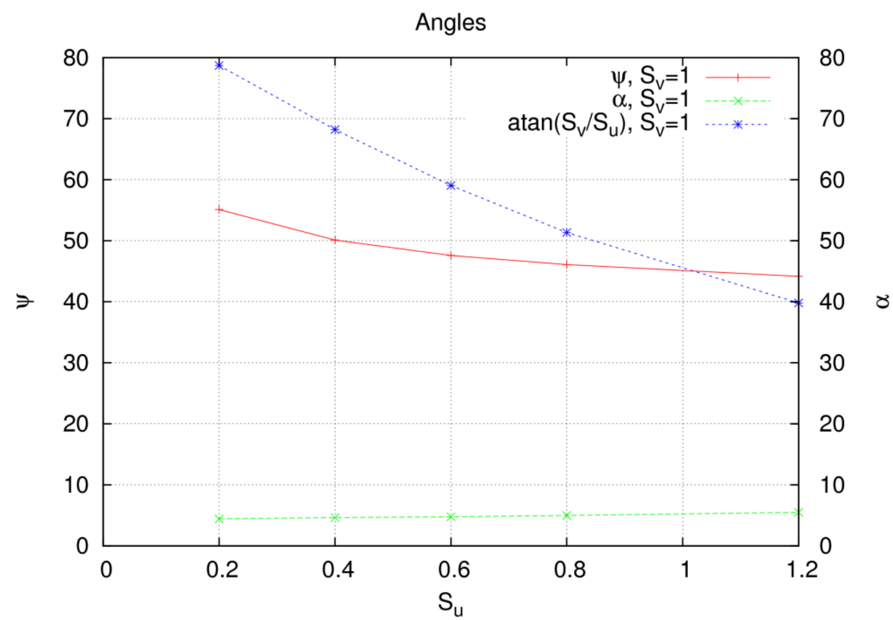


Axial pressure loss coefficient



Angles of the configuration

Conclusions

Conclusions / Our results

- Sensitivity strudies for RANS computations :
  - No effect of the tubes number
  - Only low Reynolds Number approaches seems to converge
  - Good convergence of the EBRSM model

- « Unexpected » asymmetry of the flow with a strong axial flow

- Relatively good agreement with experimental correlations

- Access to data that we couldn’t get with experimental approaches.

Conclusions / More computations to come …

- **Very fine LES** now running

- A lot of questions remain unsolved, other configurations to test

- Increase of the Reynolds Number for RANS simulation (reactor Reynolds number~500000)

- **Final goal :**
  - **Correlations between head losses in the three directions, Reynolds number and α angle**

Thanks for your attention