RANS, URANS and LES calculations through five by five mixing grids of nuclear fuel assembly

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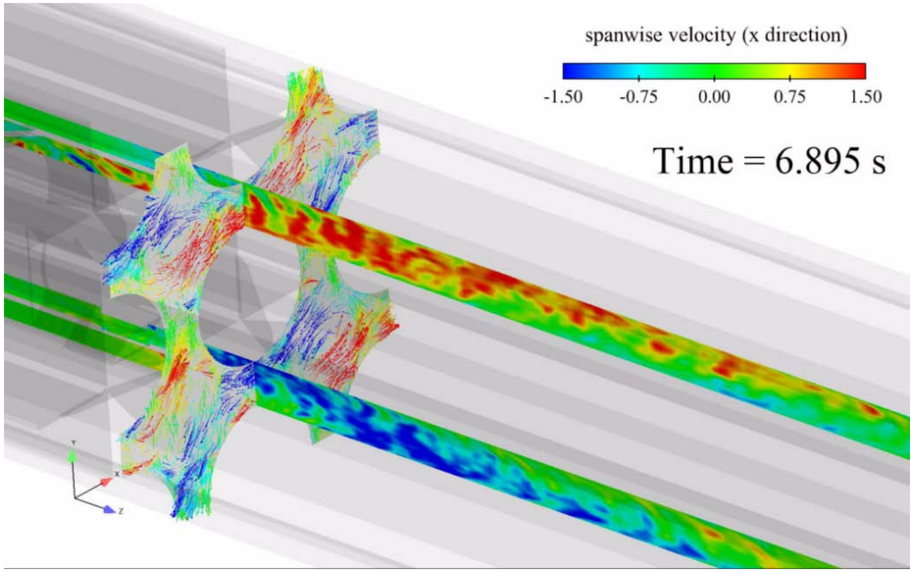
08 april 2013

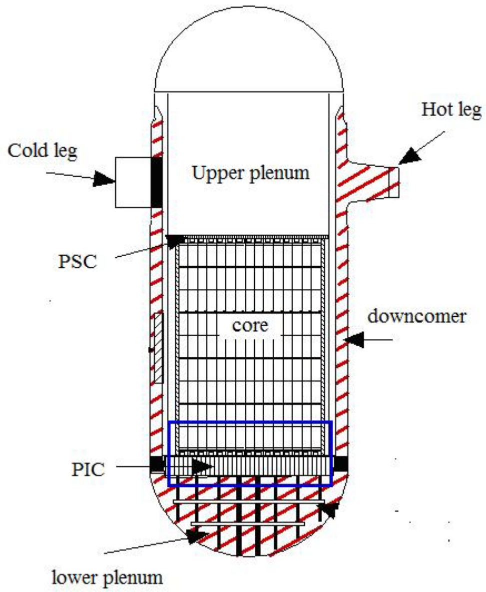


CHANGER L'ÉNERGIE ENSEMBLE

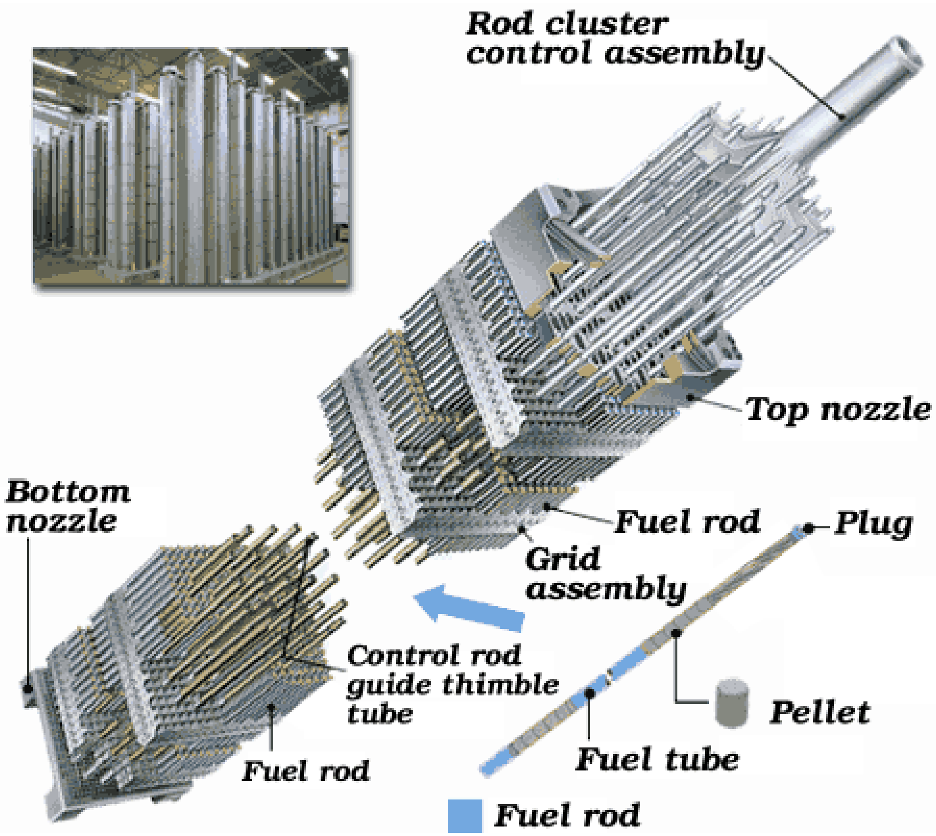
Outlook

- Fuel assemblies issues
- First LES through a 2x2 mixing grid – need for validation
- LES/URANS through 5x5 mixing grid – KAERI grid
- RANS simulations through a 5x5 mixing grid
- Conclusions and perspectives

Fuel assemblies issues



4m
8 to 10
mixing grids



Mixing grid (17x17 tubes)

Fuel assembly

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 problems

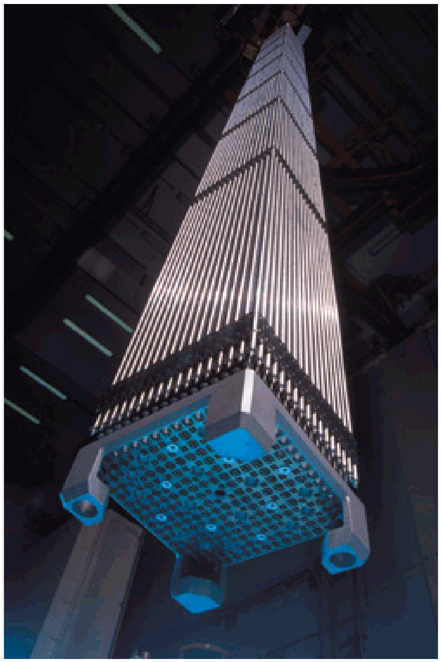
Deformations

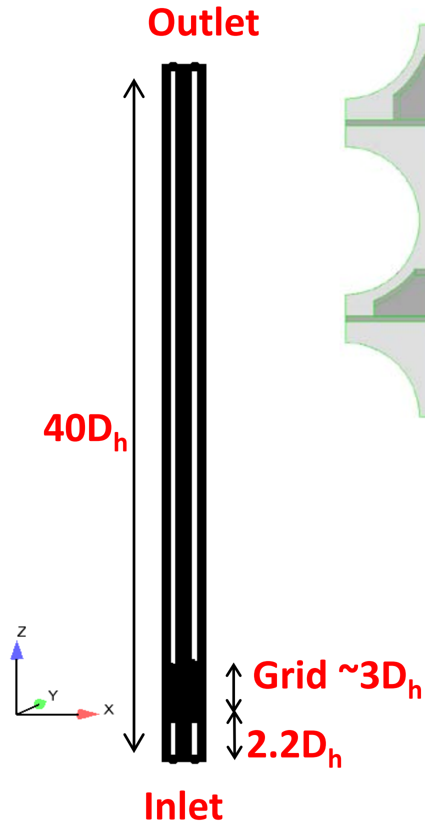
Fretting (vibrations)

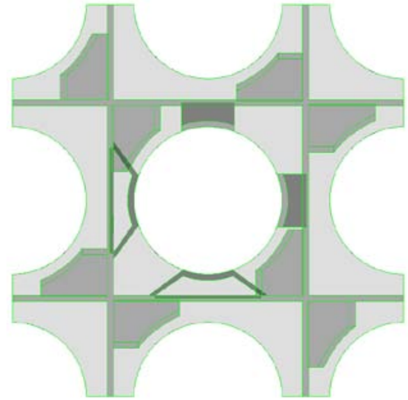
Fuel assemblies issues

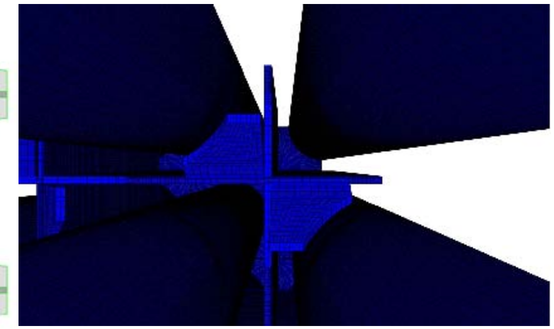
- **Complex geometry**
- **Different Fuel Assembly models**
  - several producers
- **Many constraints**
  - Low head loss
  - Good heat exchange
  - Low vibration
- **Approach**
  - Use Computational Fluid Dynamics (CFD) to obtain detailed flow structures
  - Validate by comparing CFD results with experiment when available/possible on some known configurations

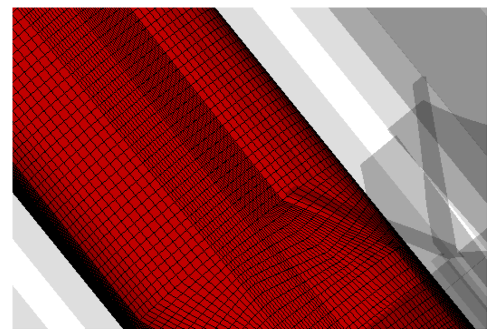
First LES through a 2x2 mixing grid











Full-hexa mesh with ICEM-CFD
8 million cells

Main parameters

- D = 9,5 mm, P/D= 1,326
- D_h=11,8 mm, Re_h= 40 000
- U_b=3,24 $m.s^{-1}$
- Standard numerical options (constant inlet)

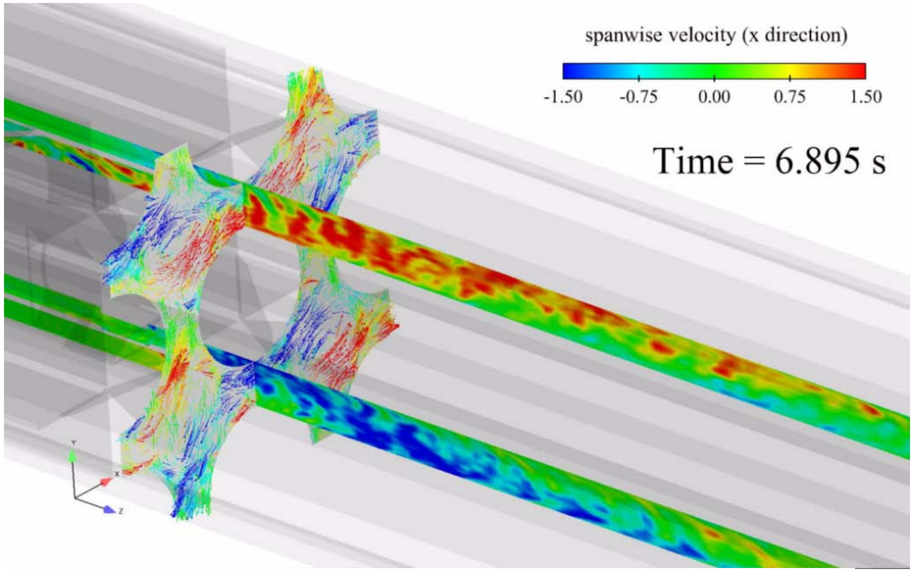
1024 procs on BlueGene/L or P - 5 s CPU/time step (CFLmax < 1)

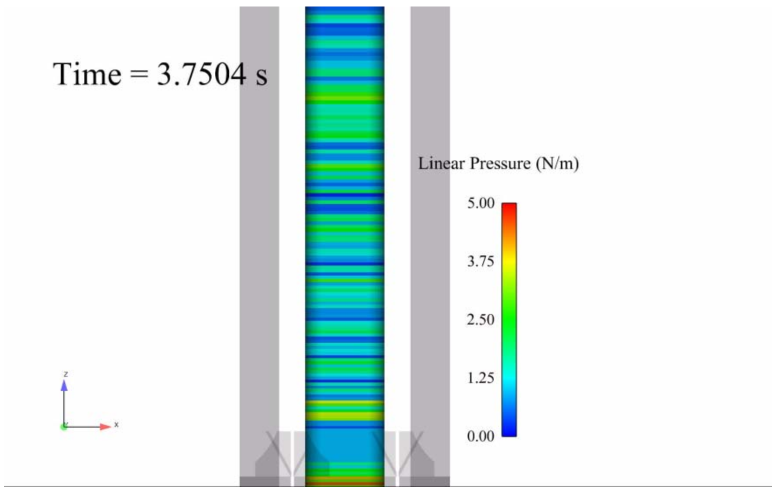
For 100 000 times steps : 1 week

Need: 5 000 000 time steps (200 passes, 5 s)

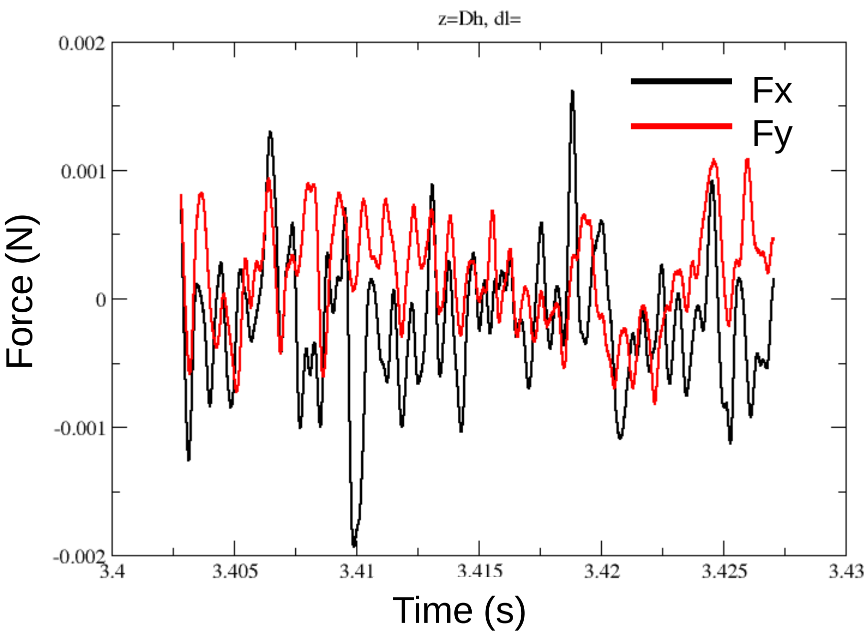
The present mesh requires the use of wall functions

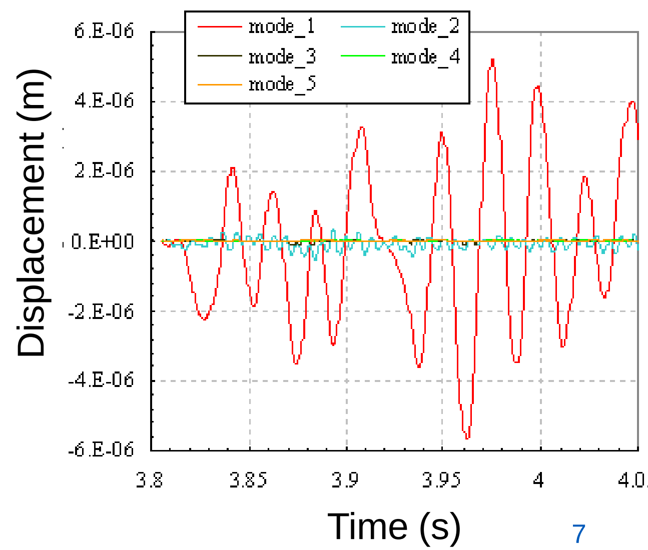
First LES through a 2x2 mixing grid





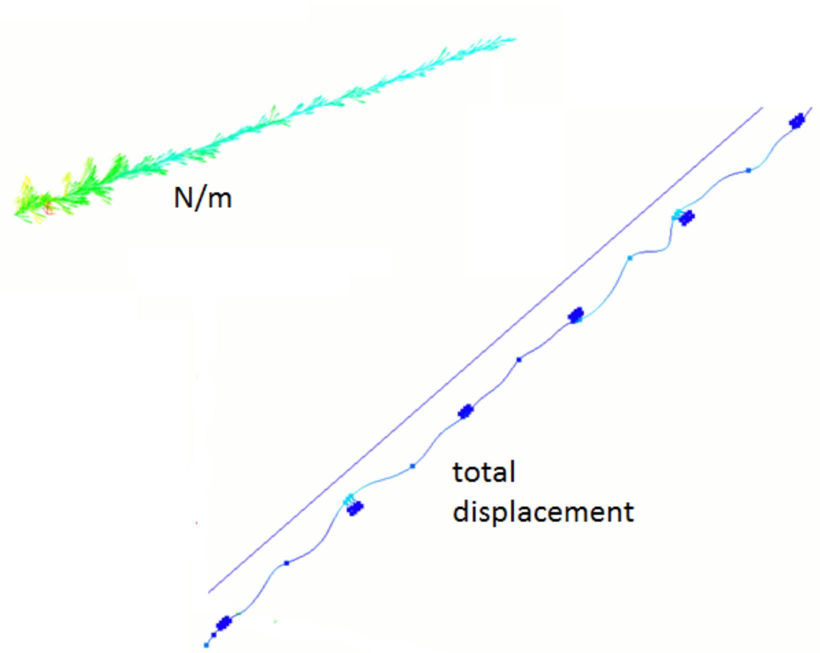
$$\left(m_{add} + \frac{\lambda L}{2}\right)\frac{d^2 a_n}{dt^2} + \frac{n^4 \pi^4 EI}{2L^3} a_n = F_n(t)$$



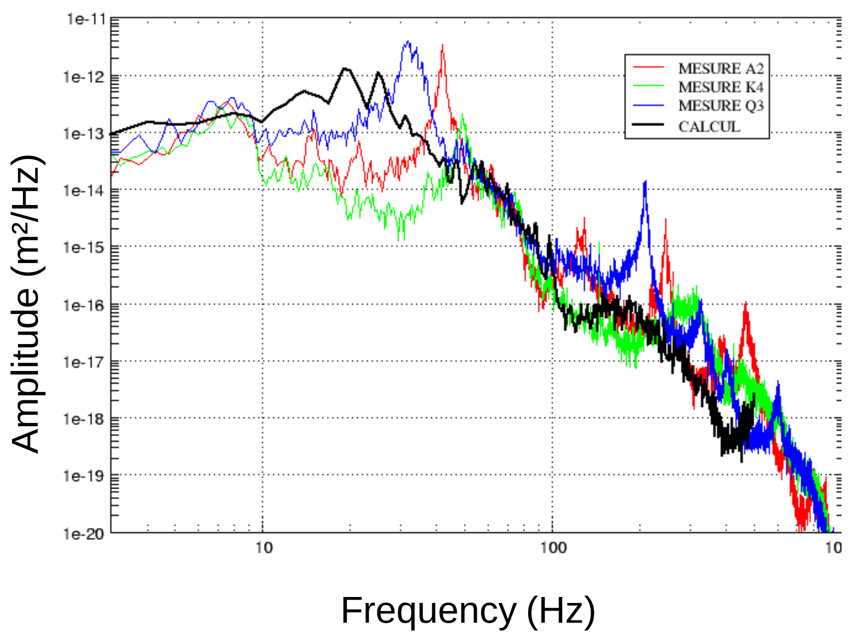


First LES through a 2x2 mixing grid

- LES seems reliable, the qualitative results are satisfactory (displacement of few microns)
- Need for validation

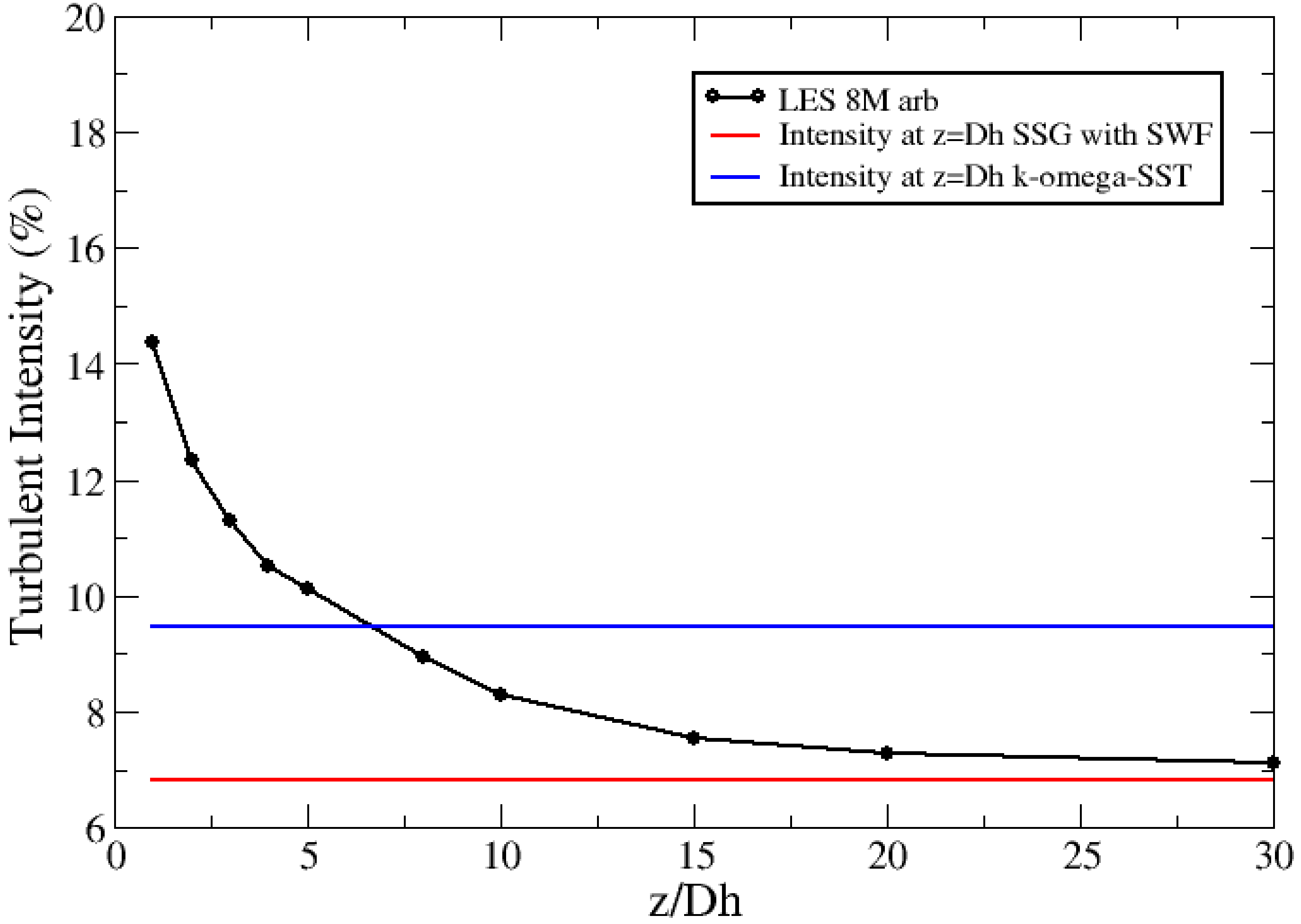


DSP : comparison to experimental results (1st span)



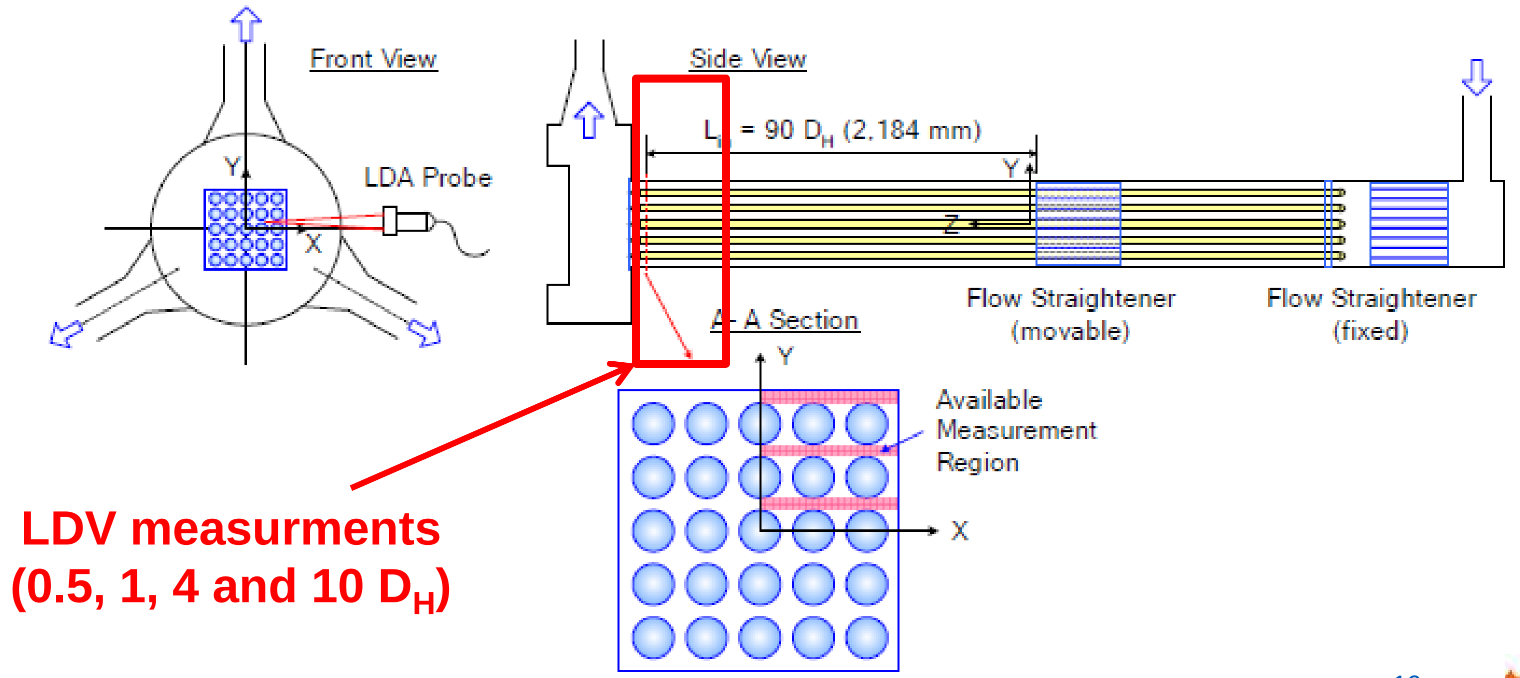
First LES through a 2x2 mixing grid

- Observation : RANS models underestimate the turbulent kinetic energy on this case



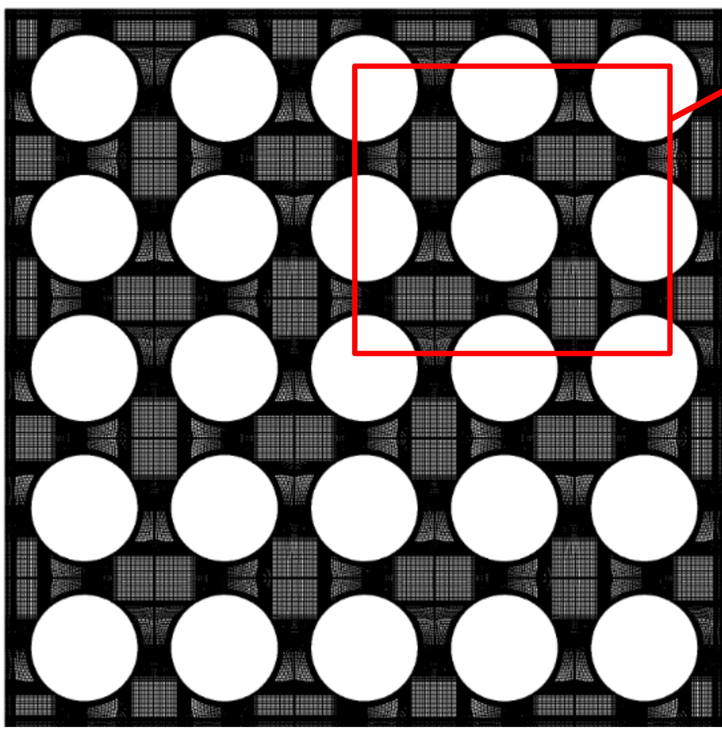
LES/URANS through 5x5 mixing grid – KAERI grid

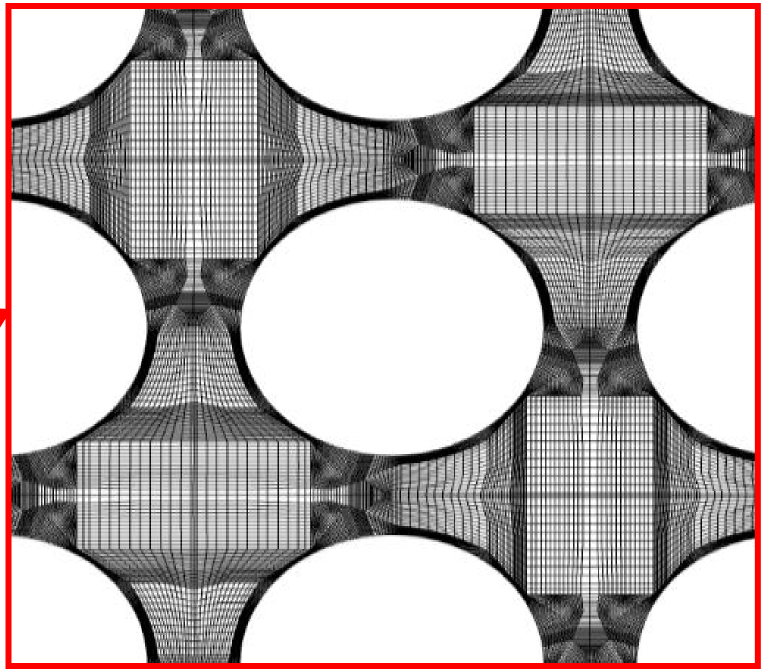
- KAERI experiment MATHIS-H (horizontal)
- Benchmark organized by OECD
- Split-type vane, 5x5 mixing grid, scale 2.67
- Few doubts about the symmetry of the configuration (the grid is too close to the outlet)



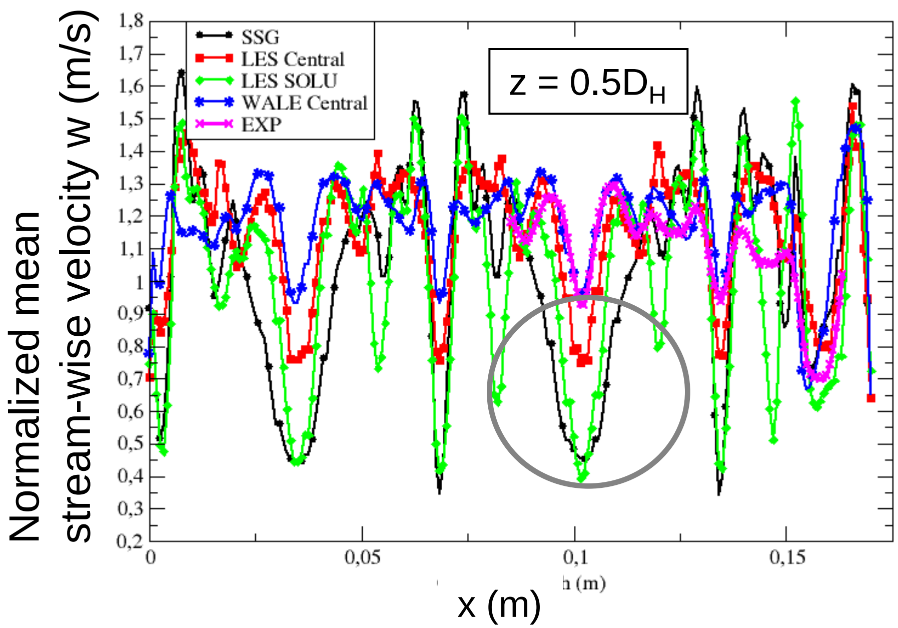
LES/URANS through 5x5 mixing grid – KAERI grid

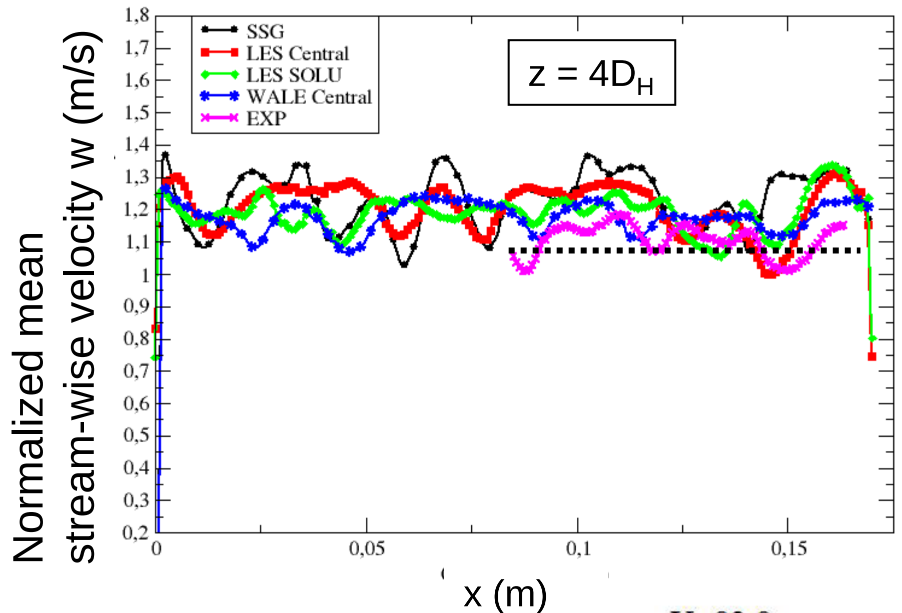
- Reynolds number Re_H=50000
- 62 Million cells



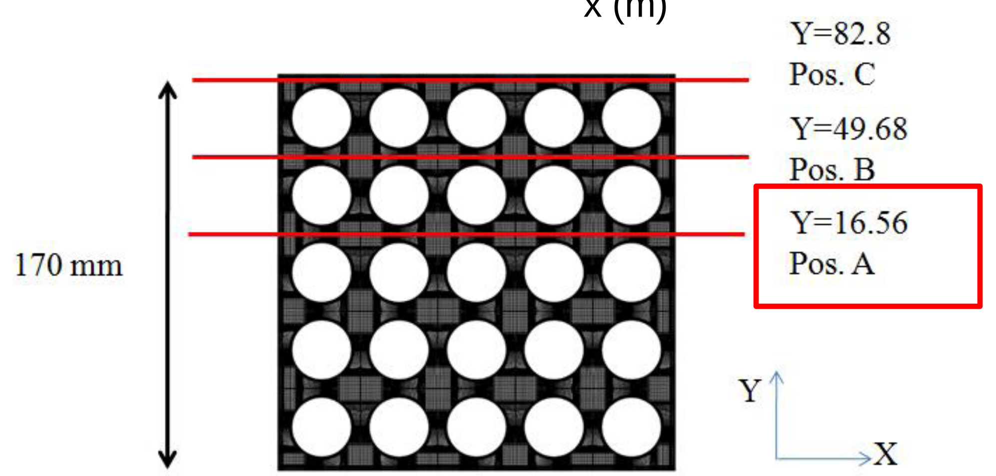


LES/URANS through 5x5 mixing grid – KAERI grid

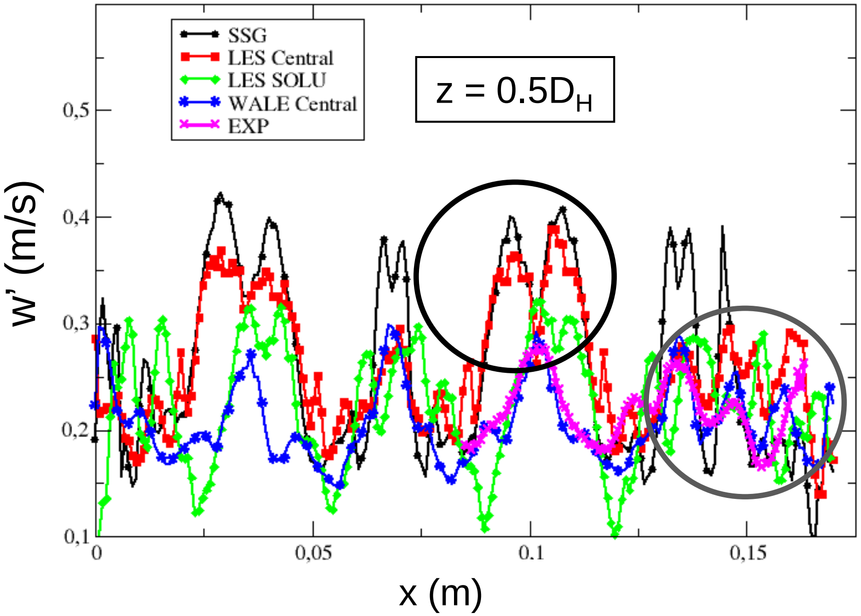


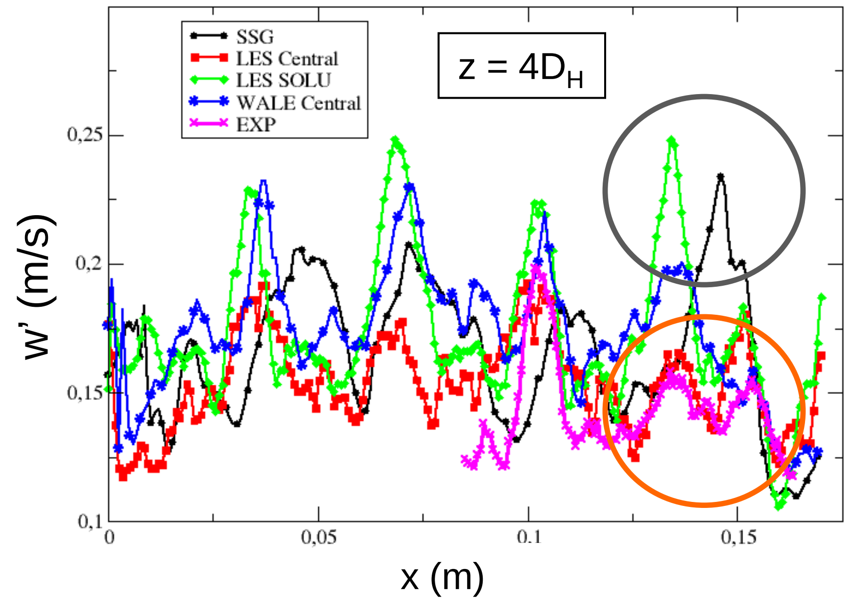


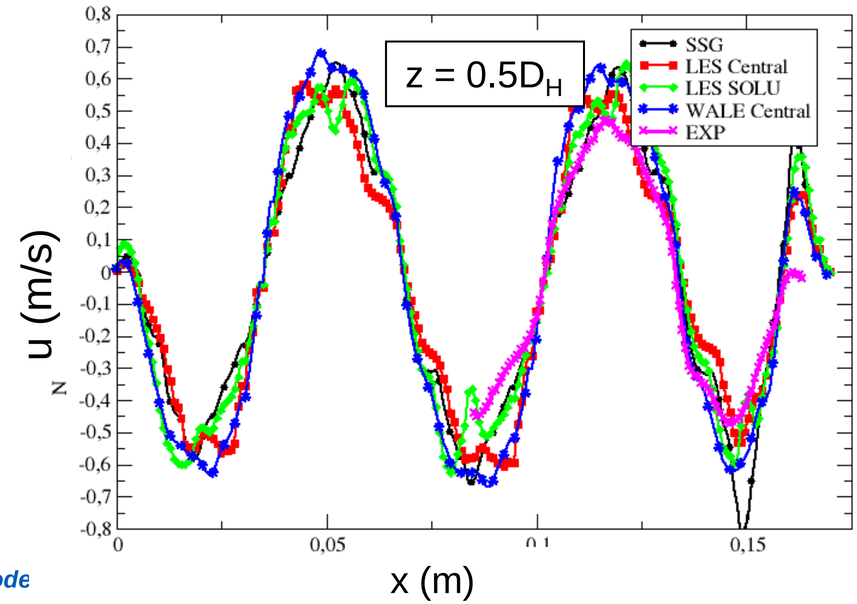
- LES (Dynamic or Wale) with the pure centered scheme gives the best compromise
- Wale model seems at first sight better than the dynamic model
- LES with Second Order Linear Upwind and URANS (SSG 2nd moment closure) both overestimate the deficit of the stream-wise velocity

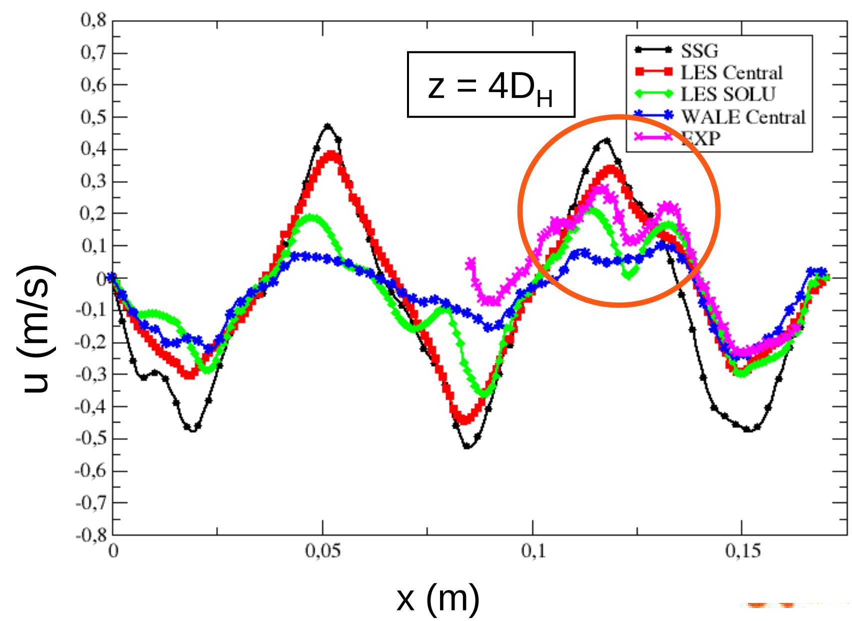


LES/URANS through 5x5 mixing grid – KAERI grid

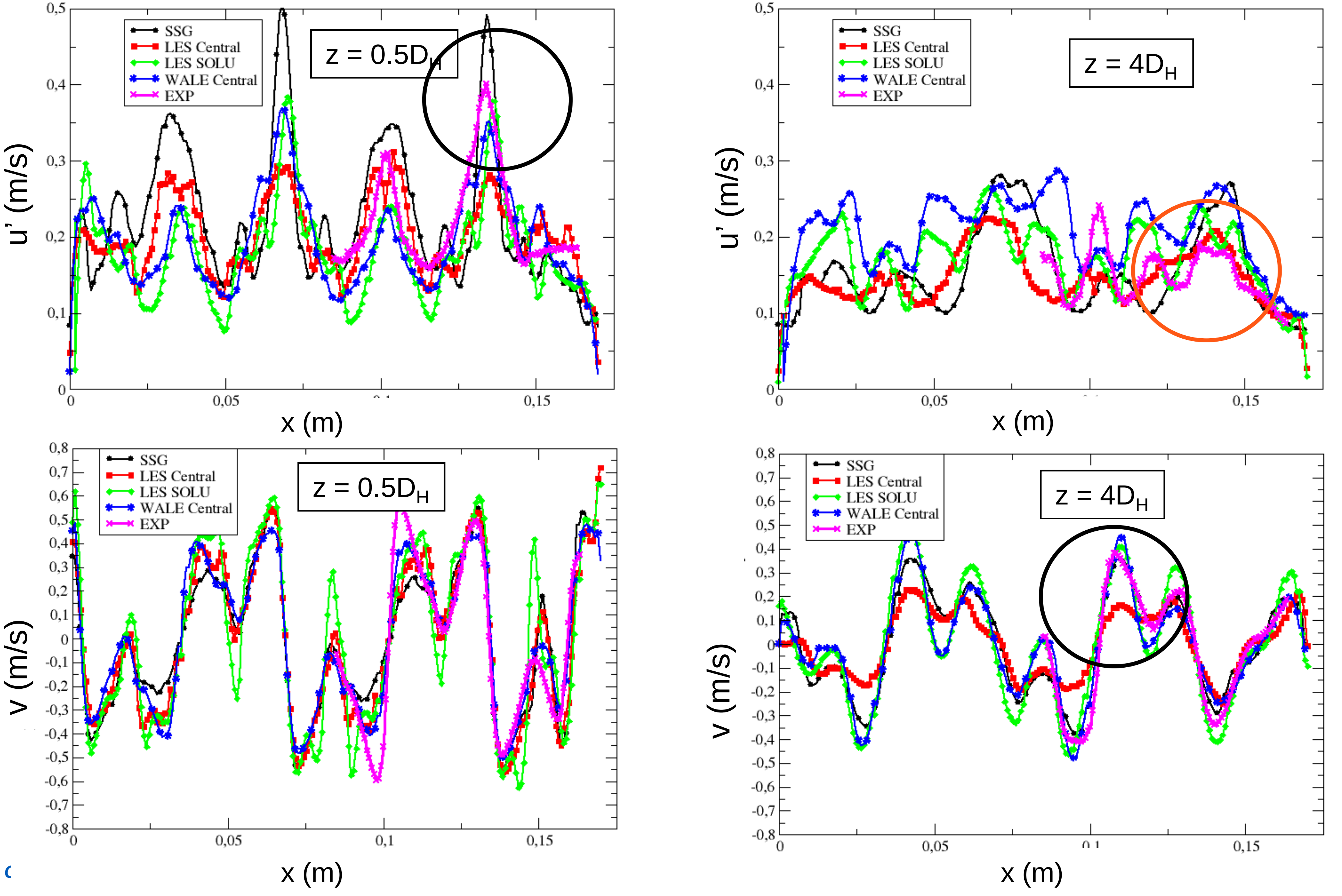




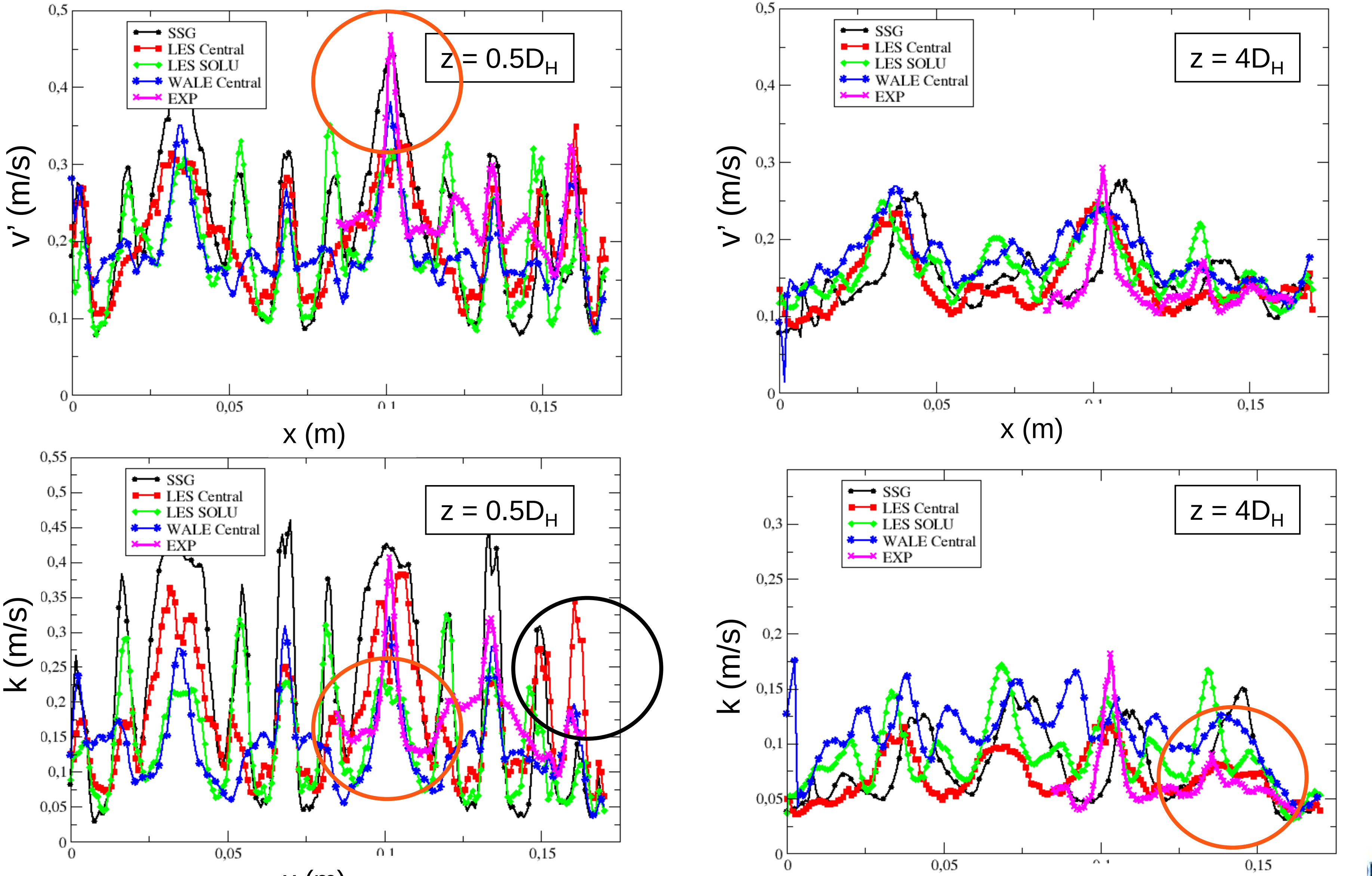




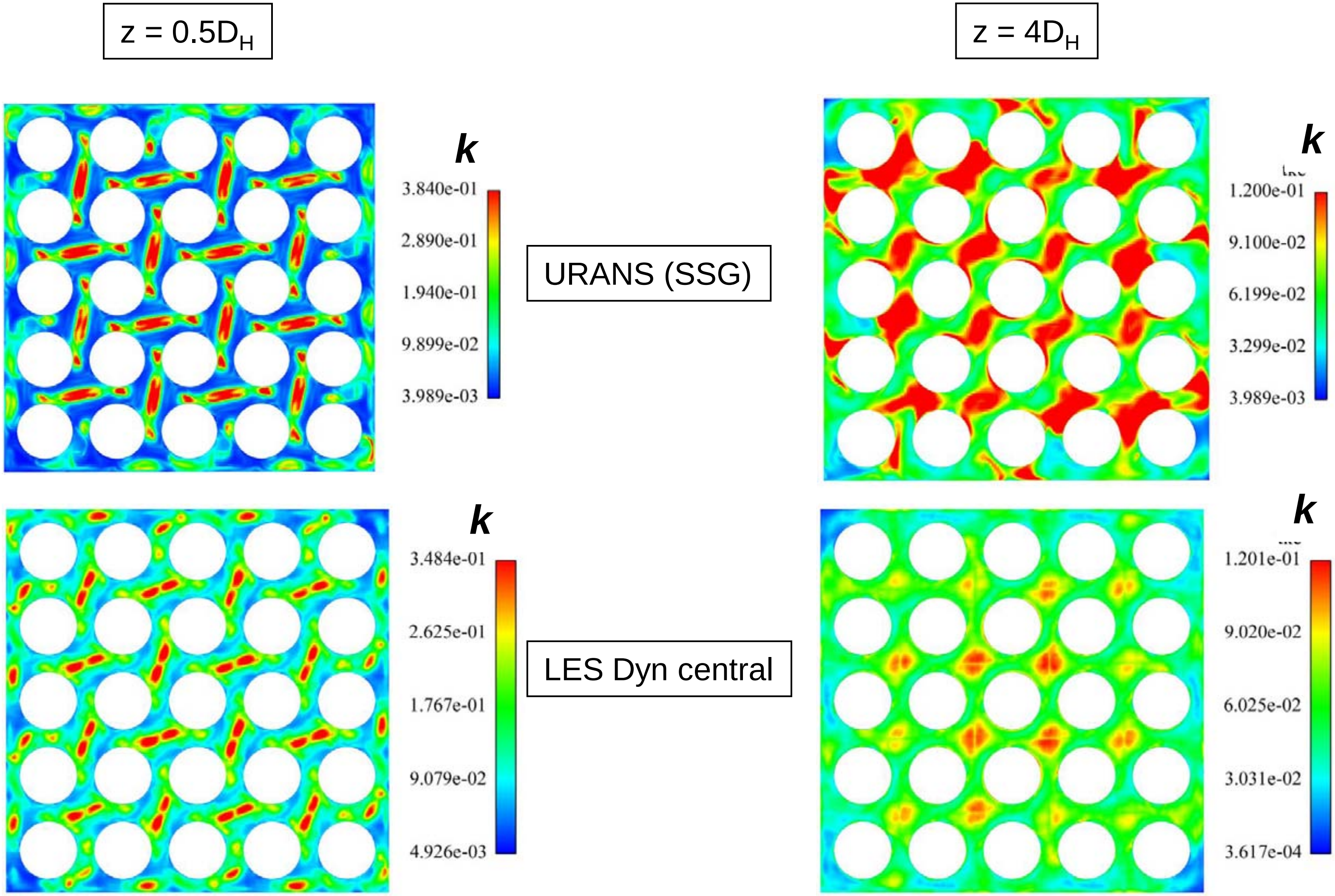
LES/URANS through 5x5 mixing grid – KAERI grid



LES/URANS through 5x5 mixing grid – KAERI grid



LES/URANS through 5x5 mixing grid – KAERI grid

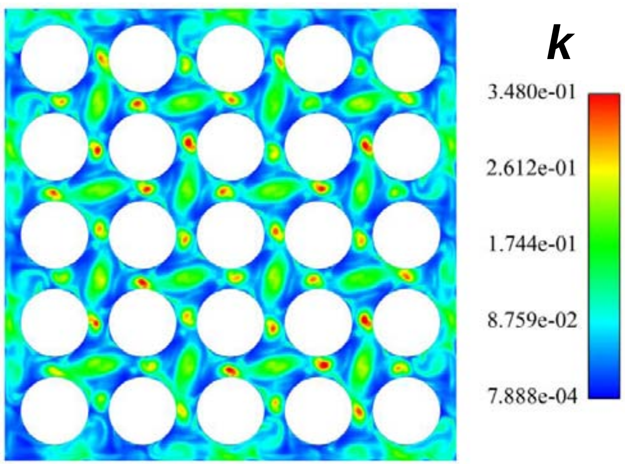


- ❑ LES with a pure centered scheme is the only one showing a split-like vane behavior with the turbulent kinetic energy

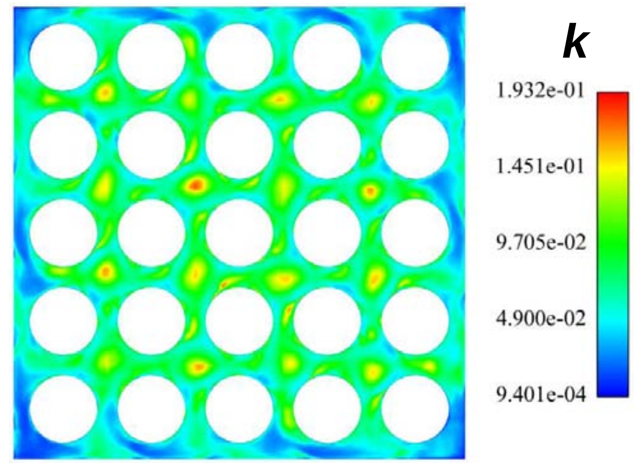
LES/URANS through 5x5 mixing grid – KAERI grid

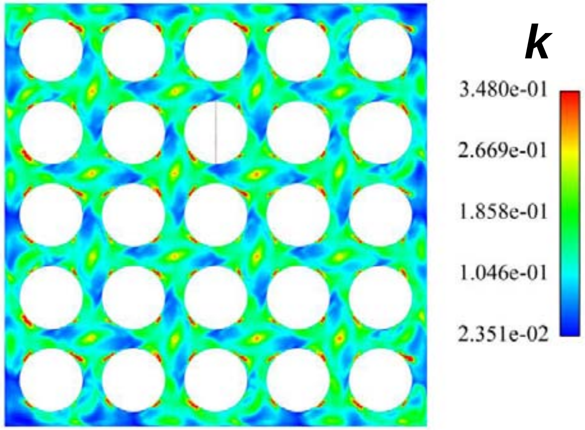
$z = 0.5D_H$

$z = 4D_H$

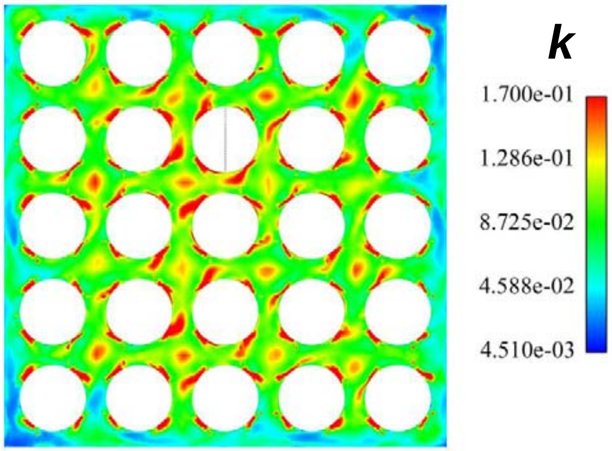


LES central SOLU



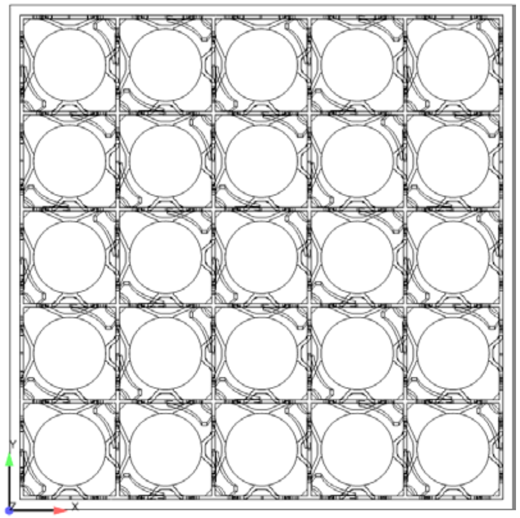


LES Wale central

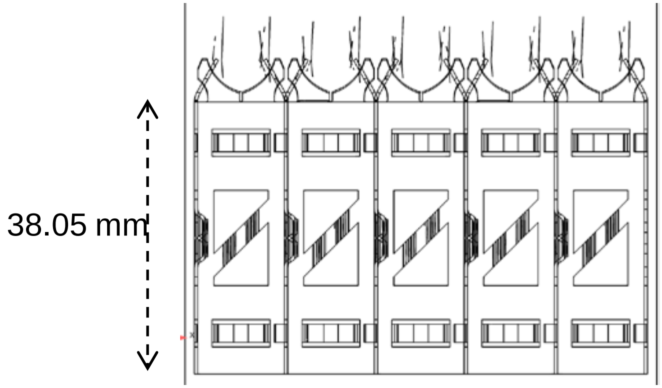


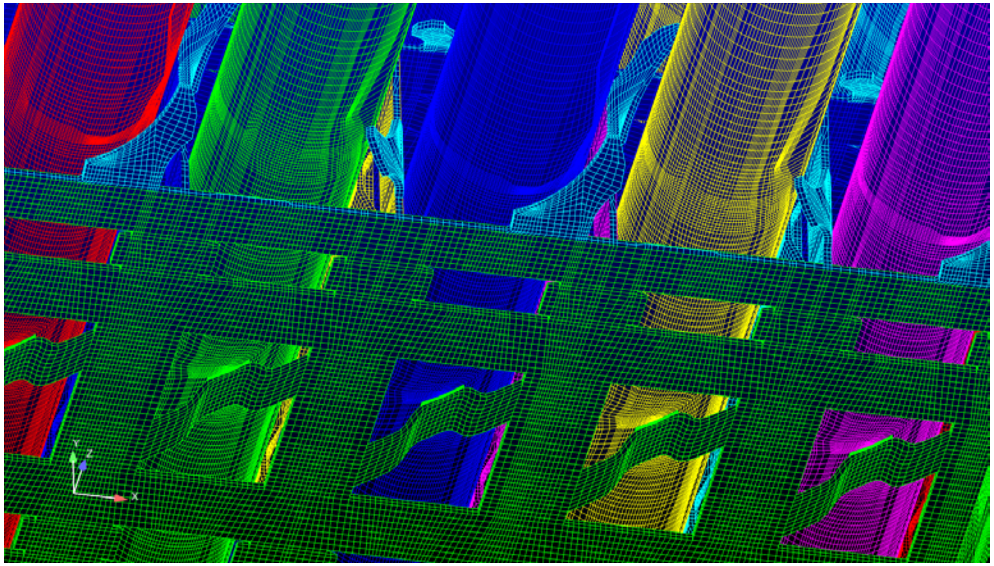
RANS simulation through a 5x5 mixing grid

- This is a part of a benchmark organized by EPRI (Manivel experiment conducted at EDF)



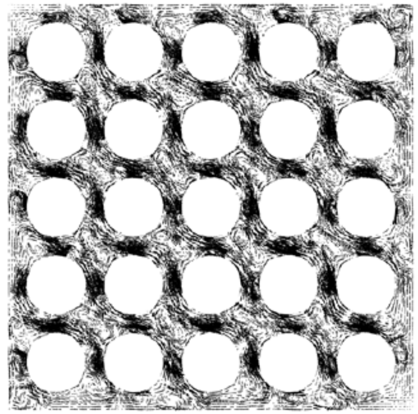
Orientation O1





Fully hex mesh

RANS simulation through a 5x5 mixing grid



Main characteristics :

Re_H=100 000

Bulk velocity : U_b= 6,8 m/s

Hydraulic diameter D_H= 11,78 mm

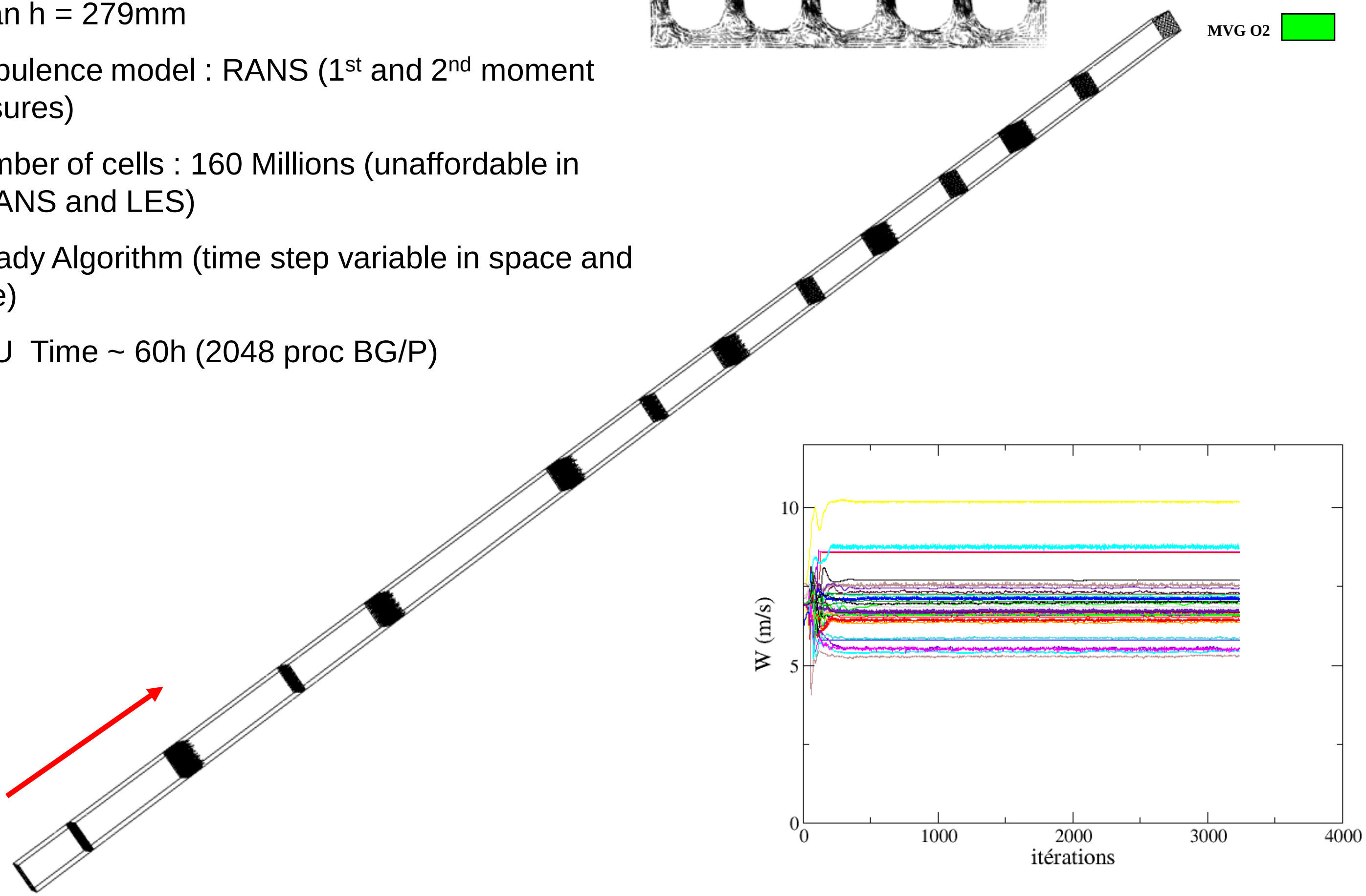
Span h = 279mm

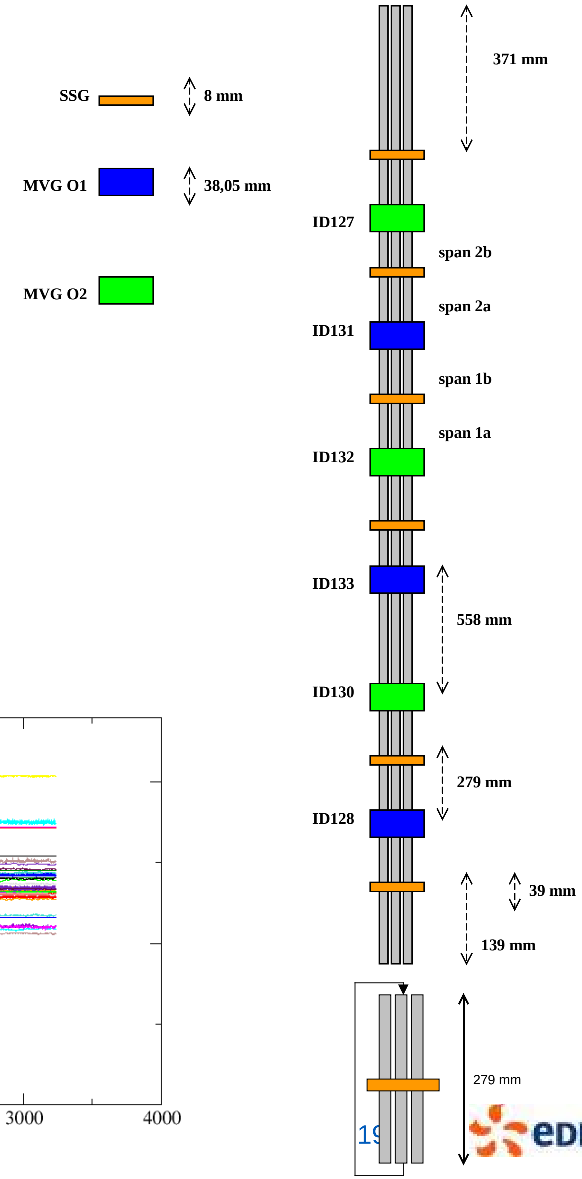
Turbulence model : RANS (1st and 2nd moment closures)

Number of cells : 160 Millions (unaffordable in URANS and LES)

Steady Algorithm (time step variable in space and time)

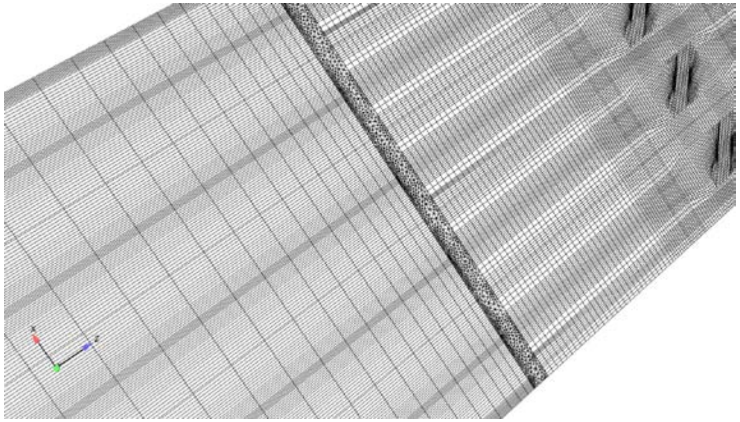
CPU Time ~ 60h (2048 proc BG/P)



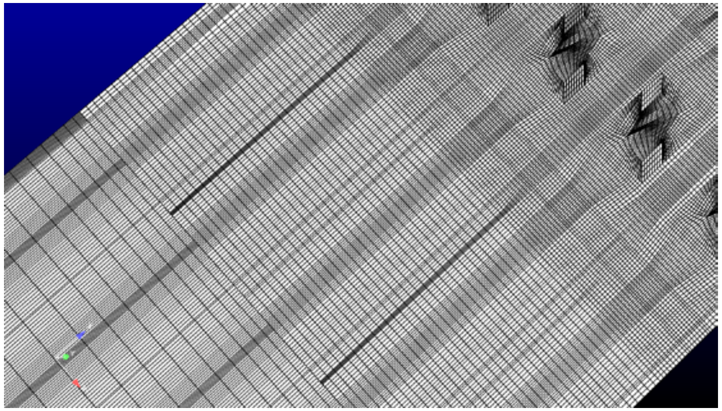


RANS simulation through a 5x5 mixing grid

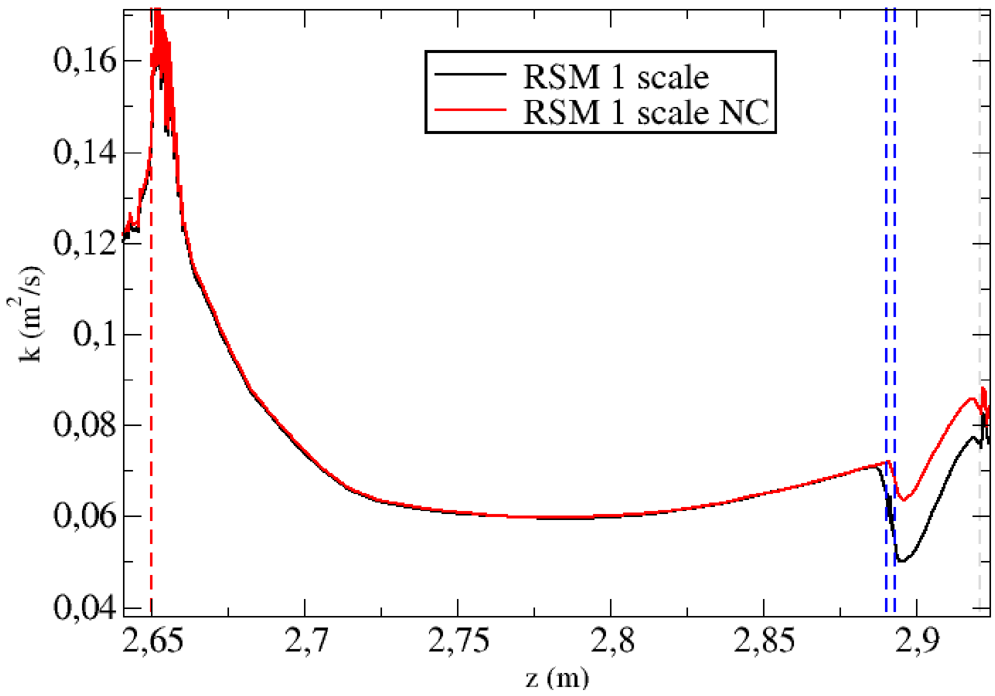
- 2 types of junctions between the two different grids :
  - conforming junction with mixed elements (hex, tets and pyramids
  - Non-conforming junction



Conforming junction

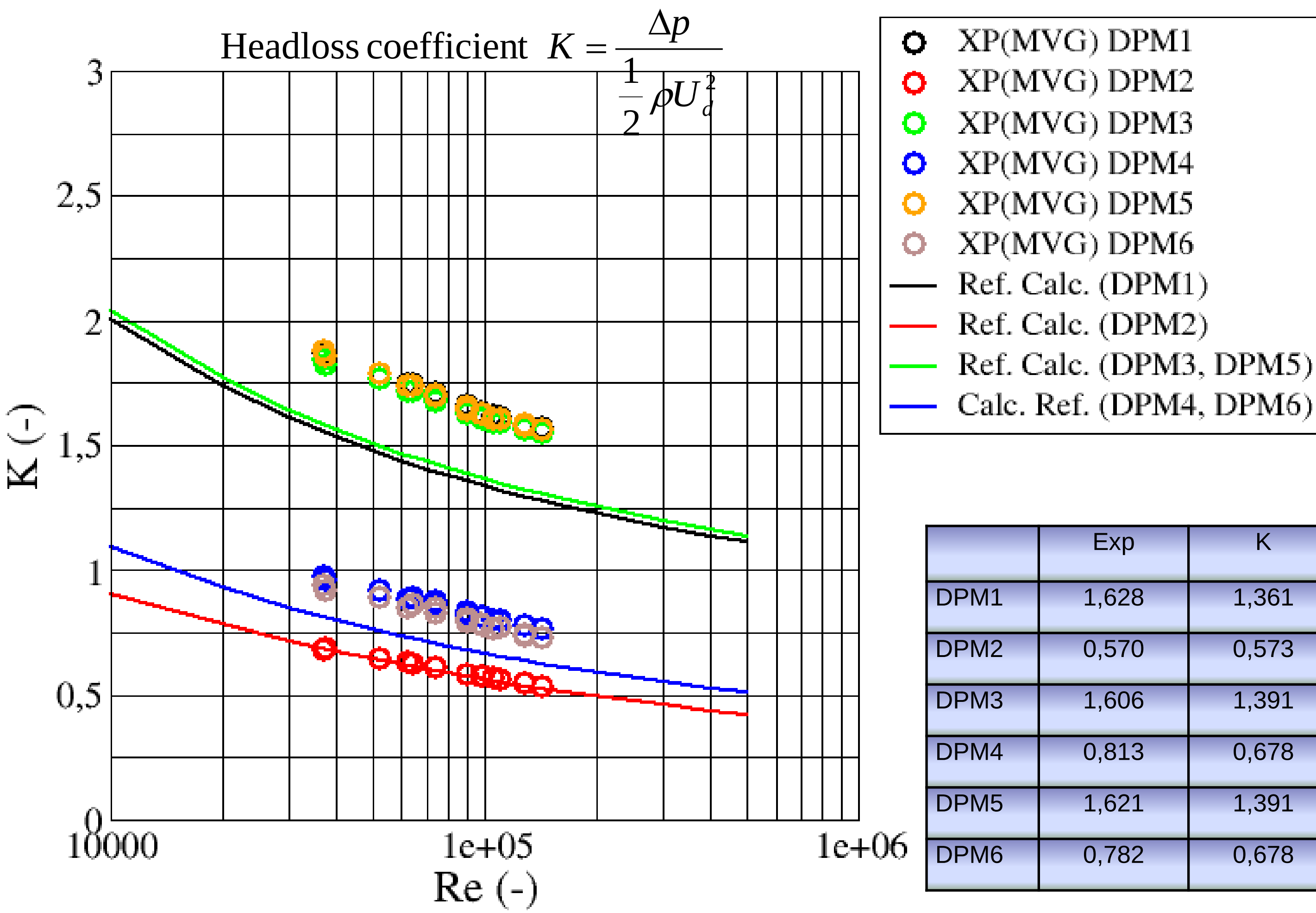


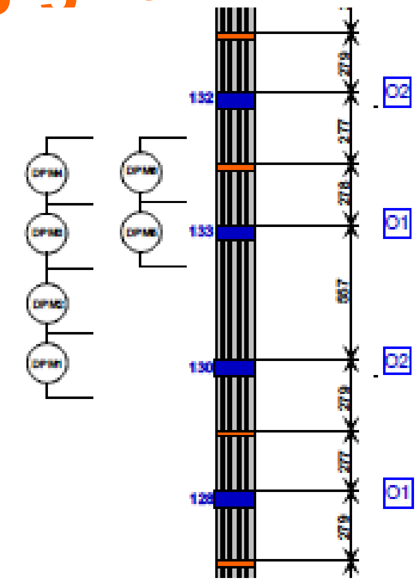
Non-conforming junction



Turbulent kinetic energy evolution

RANS simulation through a 5x5 mixing grid





	Exp	K	error (%)
DPM1	1,628	1,361	-16,41
DPM2	0,570	0,573	0,46
DPM3	1,606	1,391	-13,43
DPM4	0,813	0,678	-16,62
DPM5	1,621	1,391	-14,23
DPM6	0,782	0,678	-13,39

- Results with 2nd moment closure and a standard wall function with 1 velocity scale
- Global underestimation of the headloss coefficient except for the bare bundle
- Same results with the two types of junction

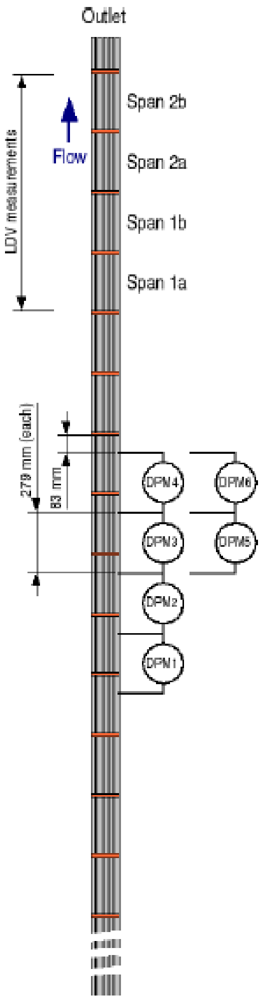
RANS simulation through a 5x5 mixing grid

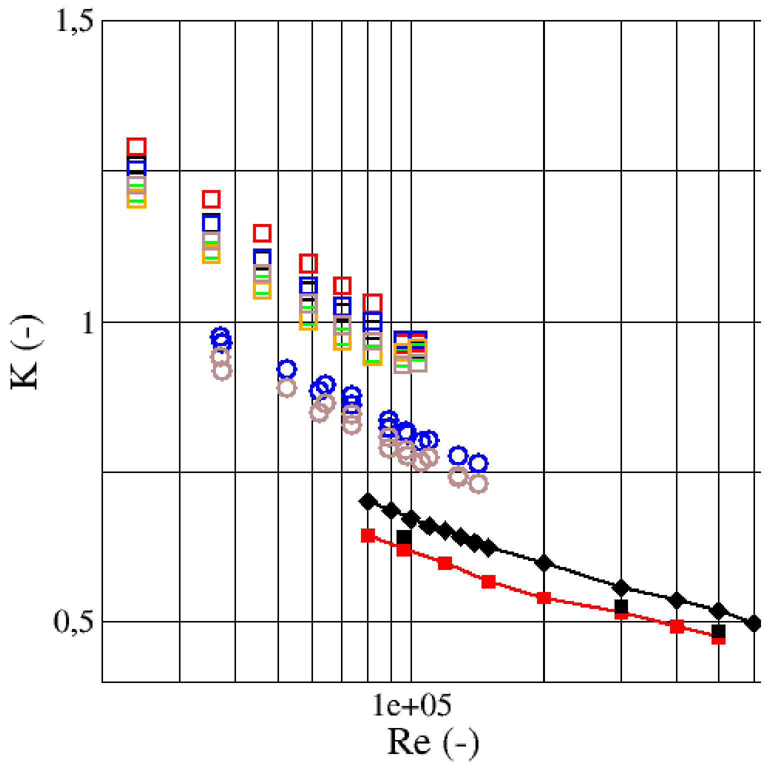
	Exp	RSM 1 *scale*	k-ε 2 *scales*	k-ε 1 scale	RSM 2 scales	kω-SST
DPM1	1,628	1,361	1,107	1,412	1,011	1,115
DPM2	0,570	0,573	0,417	0,584	0,387	0,444
DPM3	1,606	1,391	1,089	1,440	0,993	1,126
DPM4	0,813	0,678	0,562	0,708	0,521	0,554
DPM5	1,621	1,391	1,089	1,440	0,993	1,126
DPM6	0,782	0,678	0,562	0,708	0,521	0,554

- Sensitivity to the turbulence model and wall functions
  - 1 scale results are closer to the experimental data
  - Is this phenomena due to the junctions?

RANS simulation through a 5x5 mixing grid

- With only simple grids (conforming mesh), the results concerning the under-estimation of the head-loss coefficient are worse! And there is still an underestimation with the wall function using 2 scales …





	Exp	K	Error (%)
DPM1	0,96	0,62	-35,31
DPM2	0,96	0,62	-35,09
DPM3	0,93	0,62	-33,51
DPM4	0,96	0,62	-35,53
DPM5	0,94	0,62	-34,14
DPM6	0,92	0,62	-32,72

	Exp	Calc. Ref.	k-ε	kω-SST	RSM 2 scales	RSM SWF
DPM1	0,948	0,67	0,67	0,67	0,63	0,63
DPM2	0,958	0,67	0,67	0,67	0,63	0,63
DPM3	0,943	0,67	0,67	0,67	0,63	0,63
DPM4	0,964	0,67	0,67	0,67	0,63	0,63
DPM5	0,950	0,67	0,67	0,67	0,63	0,63
DPM6	0,925	0,67	0,67	0,67	0,63	0,63

Conclusions and perspectives

- RANS does not seem adequate to predict the flow through mixing grids (neither for head-loss coefficient nor for turbulent kinetic energy level)

- URANS might be used (good qualitative behavior) but given an over-estimation of the turbulent kinetic energy what is not suitable if one expects to study vibrations or heat transfer

- LES with a pure centered scheme and a dynamic Smagorinsky model gave the best quantitative results for the KAERI grid used during the OECD benchmark

- LES gave good qualitative behavior for vibration predictions

- More validation is still needed in particular concerning the pressure along the rods