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LES and Hybrid RANS/LES of turbulent flow parallel to a heated rod bundle

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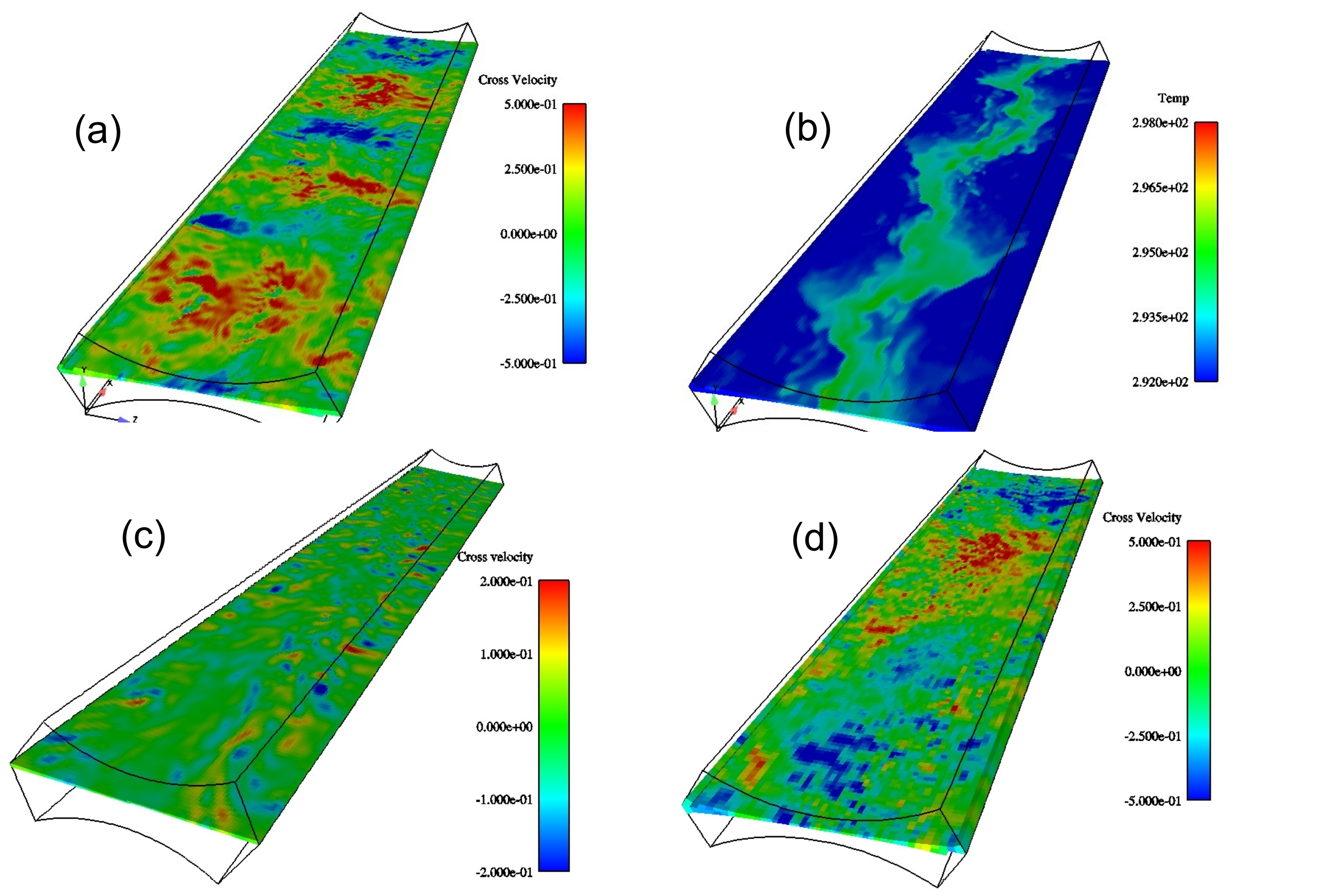
Introduction.

In most nuclear reactors, the fuel is contained in thin hollow rods arranged in square or triangular rod bundles, with fluid flowing parallel to the rods extracting the heat. High value of burn-up (neutron irradiation of the fuel) is achieved with small value of the pitch-over-diameter ratio (P/D). Experimental studies [Rehme et al. 1989, Krauss and Meyer 1998] show that turbulent intensities are quite different from those in pipes and channels. For long time the explanation was the presence of a secondary flow [Vonka 1989] as in corners of rectangular ducts. For small P/D an energetic and almost periodic azimuthal flow pulsation is present in the gap region between two sub-channels [Rowe 1974, Hooper and Rehme 1984], and induces higher mixing between sub-channels [Krauss and Meyer 1998]. These flow pulsations are described as coherent large-scale structures flowing in the stream-wise direction, with unsteady meandering off the mean flow. Steady state simulations with basic turbulence models cannot describe this type of flow, yet it can play an important role in homogenization of temperatures across the core, or in flow induced vibrations.

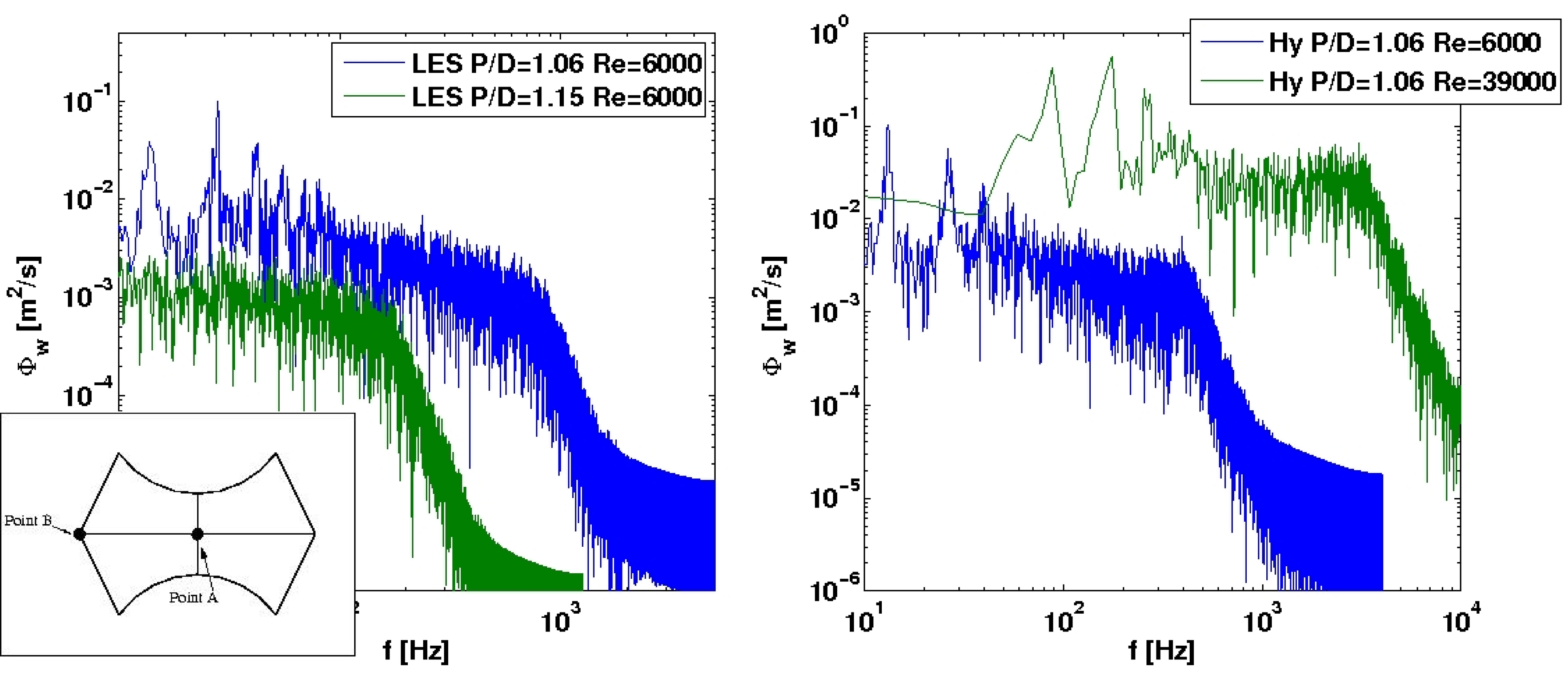
· In the present study a first low Reynolds LES shown to capture the meandering flow, then a hybrid RANS – LES approach is developed to reach the higher (industrial) Re numbers.

Flow fluctuations: effects on the thermal-hydraulic field.



Instantaneous flow fields in the mid plane A-A' : Cross velocity W (a) and temperature (b) (LES6K); (c) Cross velocity W (LESWPD); (d) Cross velocity W (HYB6K). In (a) and (d) an alternative pattern positive and negative of the velocity is very clear, meaning a strong exange between sub-channels. This phenomenon is not visible in figure (c). The results of the flow fluctuations is a meaning temperature field (b)

Flow fluctuations: spectra characterization.



Power spectra in time of the velocity fluctuation (w) in the azimuthal direction. The probe is located in the centre of the domain (point A of the small adjacent picture). The spectra, for the tight geometry, are characterized by two dominant frequencies and the dimensionless value are reported in table below

Average Results: Resume table.

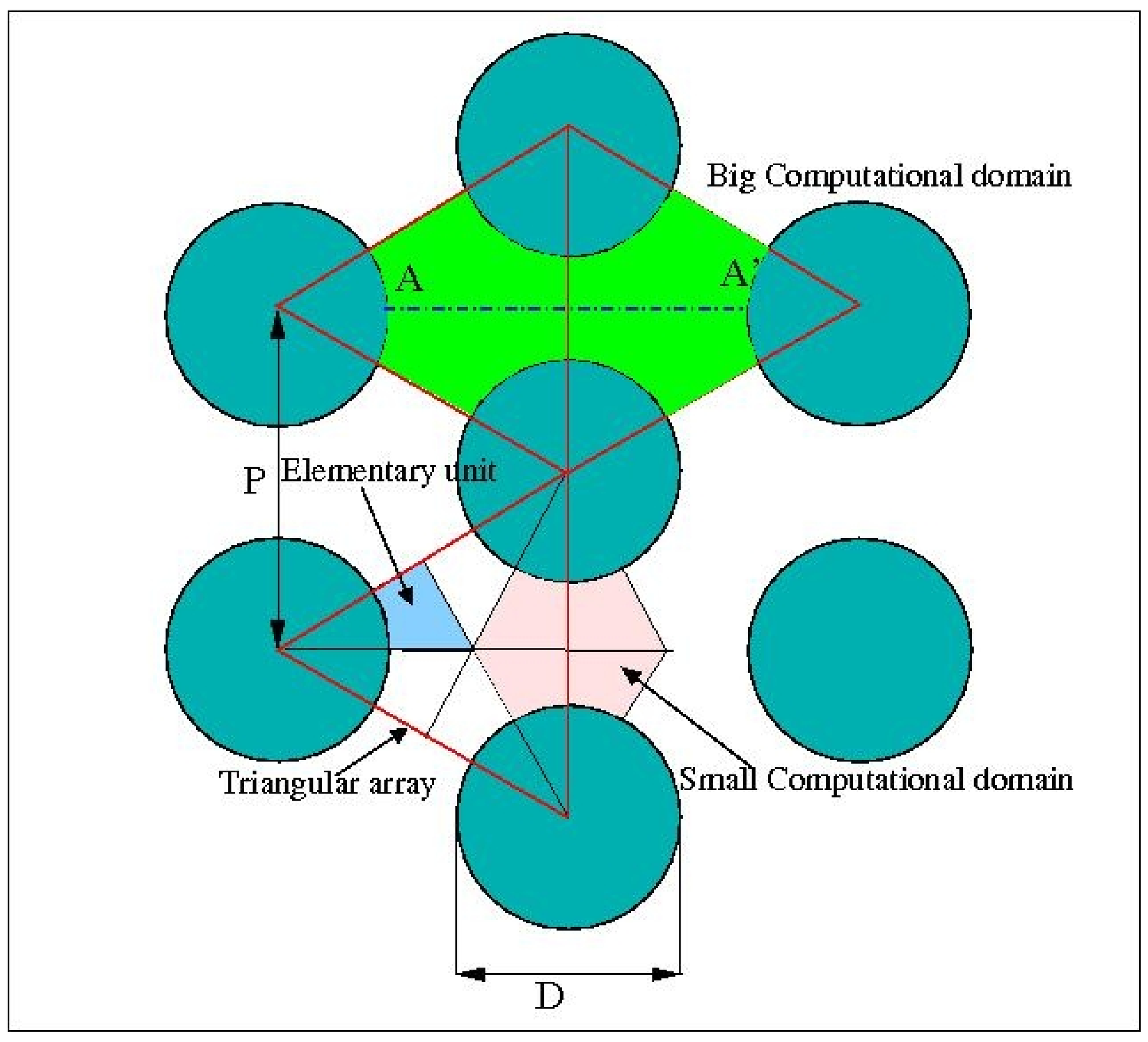
	LES6K	LESWPD	HYB6K	HYB39K	EXP
$\tau_w/0.5\rho U_B^2$	0.0086	0.0025	0.0106	0.0104	0.0057
$St=fD_h/U_{B,gap}$	0.98-1.96	/	0.91-1.85	0.92-1.94	0.93
$U_{B,gap}/U_B$	0.75	0.89	0.77	0.83	0.78

Adimesionalized mean parameters for the different cases. The experimental data are for P/D=1.06 and Re=39000 (Krauss and Meyer 1998). ($U_{B,gap}$ is the bulk velocity in the gap region.)

Rod Bundle arranged in a triangular array: case definition.

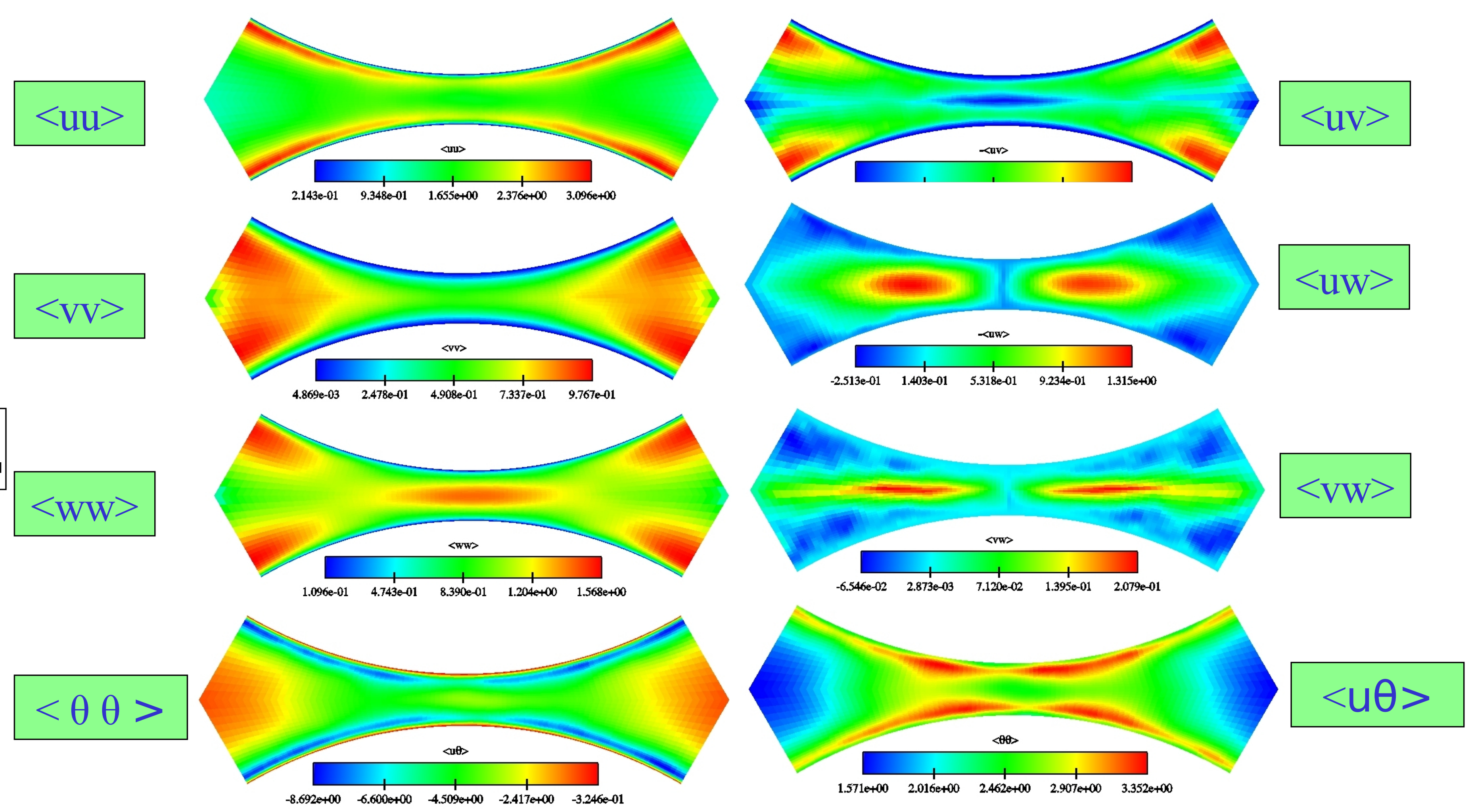
1. **P/D = 1.06**
   - **-LES @ Re = 6000** Mesh size ~ 1.6 Million cells with Heat transfer. 0.75<Δr+<1.06 7.5<rΔθ+<11 16<Δx+<22.5 (LES6K)
   - **-Hybrid @ Re = 6000** Mesh size ~ 0.35 Million cells with Heat transfer 0.8<Δr+<1.3 15<rΔθ+<20 40<Δx+<60 (HYB6K)
   - **-Hybrid @ Re = 39000** Mesh size ~ 0.9 Million cells no Heat transfer 0.8<Δr+<1.2 20<rΔθ+<25 50<Δx+<70 (HYB39K)
2. **P/D = 1.15**
   - **-LES @ Re = 6000** Mesh size ~ 1.4 Million cells no Heat transfer 0.8<Δr+<1.1 6.5<rΔθ+<10 16<Δx+<22.5. (LESWPD)

The length in the stream-wise direction is equal to 12 times the Hydraulic diameter for all the configurations.



Sketch, of the rod bundle geometry where D is the diameter of a fuel pin and P is the distance between the center of two adjacent fuel elements (pitch). In this study the small computational domain (pink) was used.

Average Results: Reynolds Stresses



Adimesionalized mean Reynolds stresses for the case LES6K. It is interesting to notice that for <ww> the maximum, in the gap region, is located in the middle of the geometry. This is a clear consequence of the flow fluctuations in the area.

Conclusions.

LES

Flow Fluctuations detected, but there is a presence of a second dominant frequency not detected by the experiments. The possible reason could be the limited domain in the cross section. Verification against a domain employing bigger cross section is on going.

Hybrid

Flow pulsations detected and dominant frequency in according with the LES. There are problems in the near wall region, possible due to the blending function used in the model.

References.

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