The KNOO Project At The University of Manchester

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CFD group

What is KNOO?

KNOO

Keeping the Nuclear Option Open

KNOO is a four-year initiative set-up to maintain and develop know-how relevant to nuclear power generation. The project consists in a close collaboration between several universities in UK and key industrial and govermental stakeholders. KNOO is founded through the "Towards a Sustainable Energy Economy Program" of Research Councils UK.

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KNOO in numbers

- Collaboration between seven universities among all UK
- Budget of £6.1 million (€7.5 million): KNOO is the single largest commitment to fission reactor research in UK in the last thirty years.
- More than 50 investigators involved
- More than 70 PhD projects financed
- Structured in four different Works Package covering all the aspects of nuclear engineering.

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Work Packages

KNOO is divided into four Work Packages:

- WP1: Fuel Thermal-hydraulics and reactor Systems;
- WP2: Materials performances and Monitoring Reactors Conditions;
- WP3: An integrate approach to waste immobilization and management;
- WP4: Safety and performances for a new generation of Reactor Design.

http://www.knoo.org/

KNOO at the School of MACE - CFD

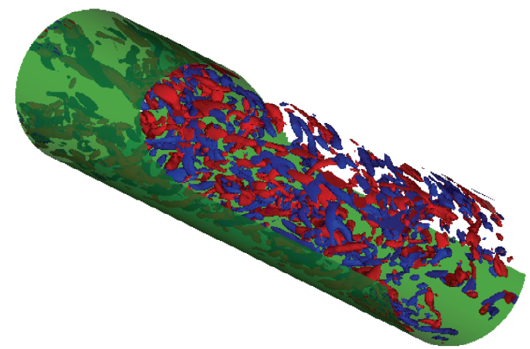
Activities of the MACE CFD Group in KNOO can be divied into:

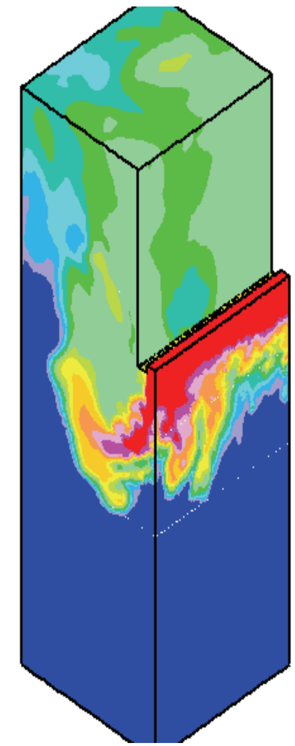
1. Creation of databases (Refined LES) for RANS validation
   - KNOO Test cases (Heat Transfer) http://cfd.mace.manchester.ac.uk/Main/KnooTestCases
2. Best Practise Guidelines (BPG) for CFD in nuclear applications.
   - http://cfd.mace.manchester.ac.uk/Main/KnooWorkshop
3. Generation IV design.
4. Performance improvements of actual reactor configurations
5. TWiki portal of the Project:
   - http://cfd.mace.manchester.ac.uk/Main/KnooProject

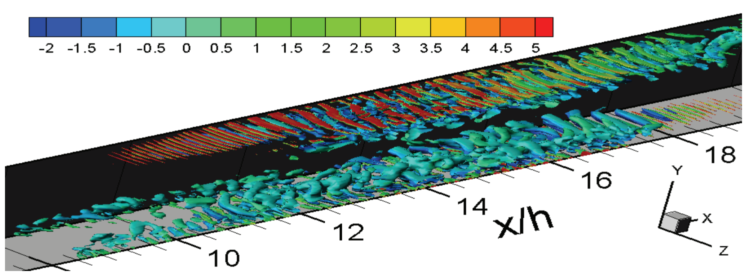
Refined LES for RANS validation (Y. Addad)

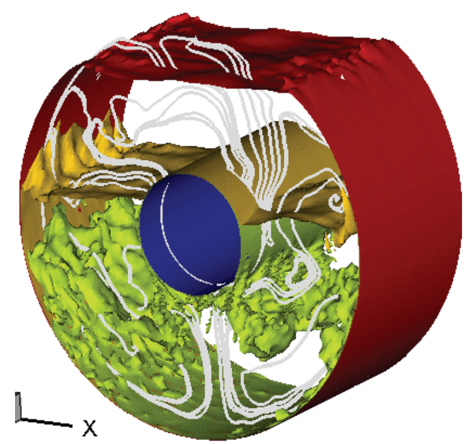
Refined LES of Natural Convection and induced re-laminarized flow.

- Heated vertical pipe flow
- Buoyancy opposed wall jet
- Cohaxial heated cylinder
- Tilted cavity

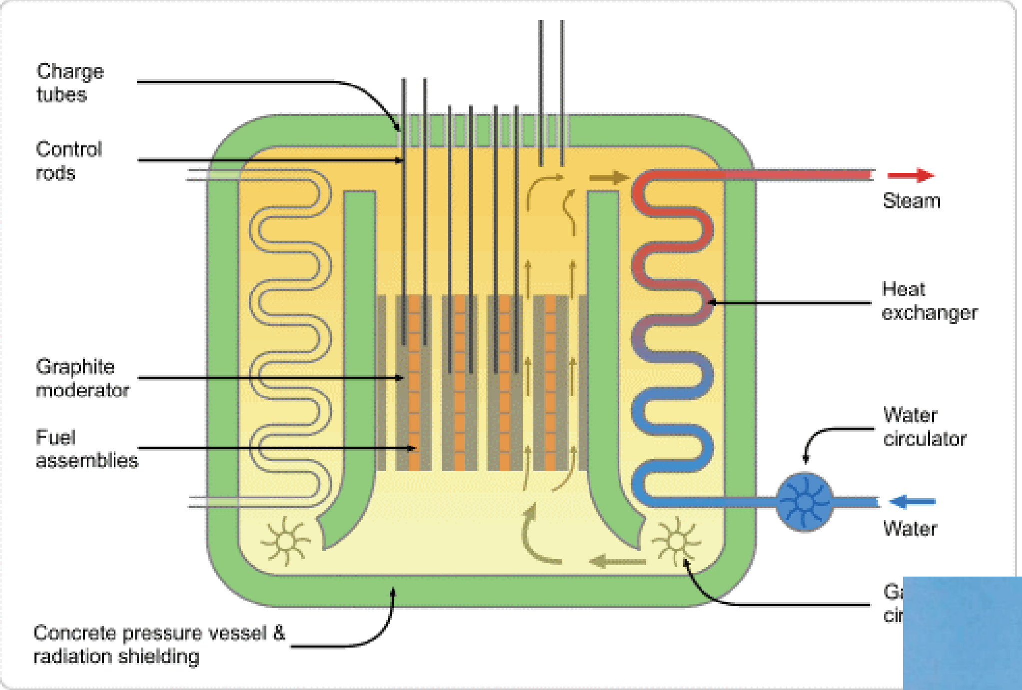








Advanced Gas Reactors (AGRs) (A. Keshmiri)



General:

- Working fluid: CO_2
- Re=1e+6 ; based on D_h
- Flow direction: Upward

Mass flow rates:

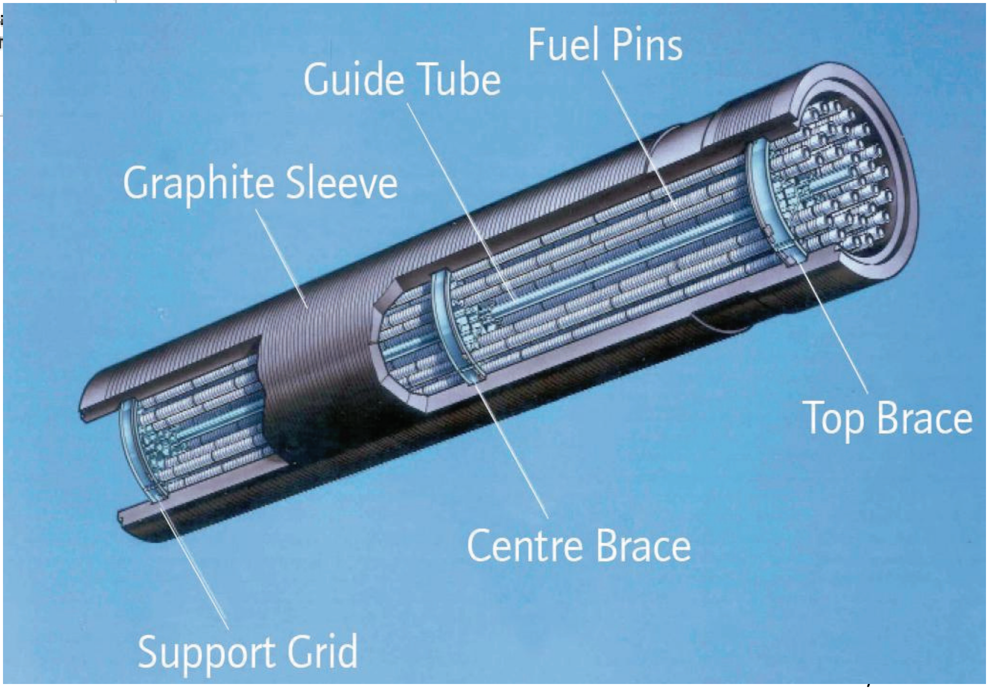
- Fuel channels: 3910 kg/s
- Net circular flow: 4270 kg/s
- Peak channel flow: 14.1 kg/s

Working bulk temperatures:

- Channel inlet: 334°C
- Channel outlet: 635°C
- Peak Temp: 661°C

Working pressures inside pressure vessel:

- Bottom slab: 45.2 bar
- Top slab and walls: 42.5 bar

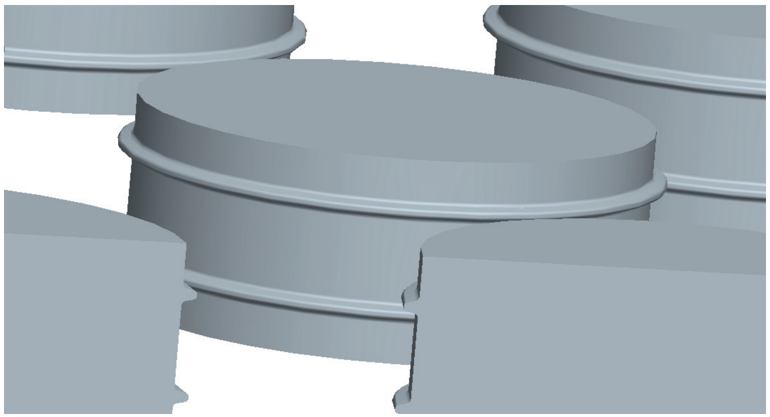


* ***"The Safety of the AGR by J M Bowerman (1982)":***

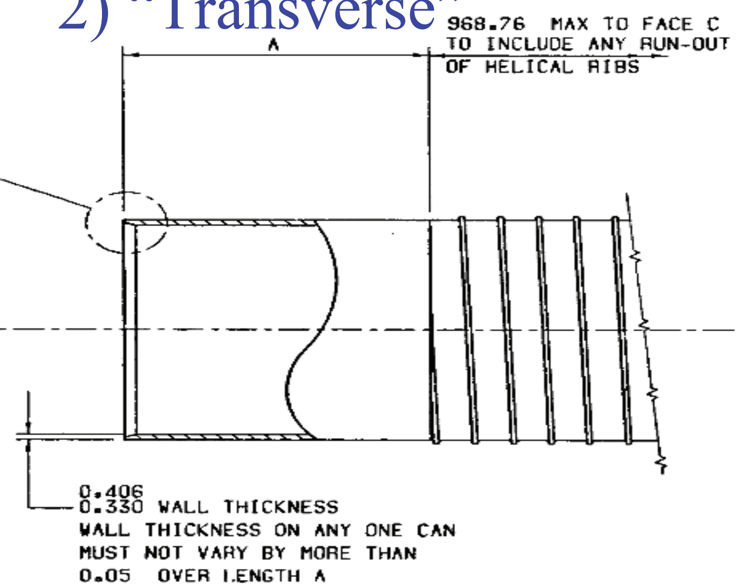
AGR fuel assembly configurations (A. Keshmiri)

Three different types of configurations for fuel pins:

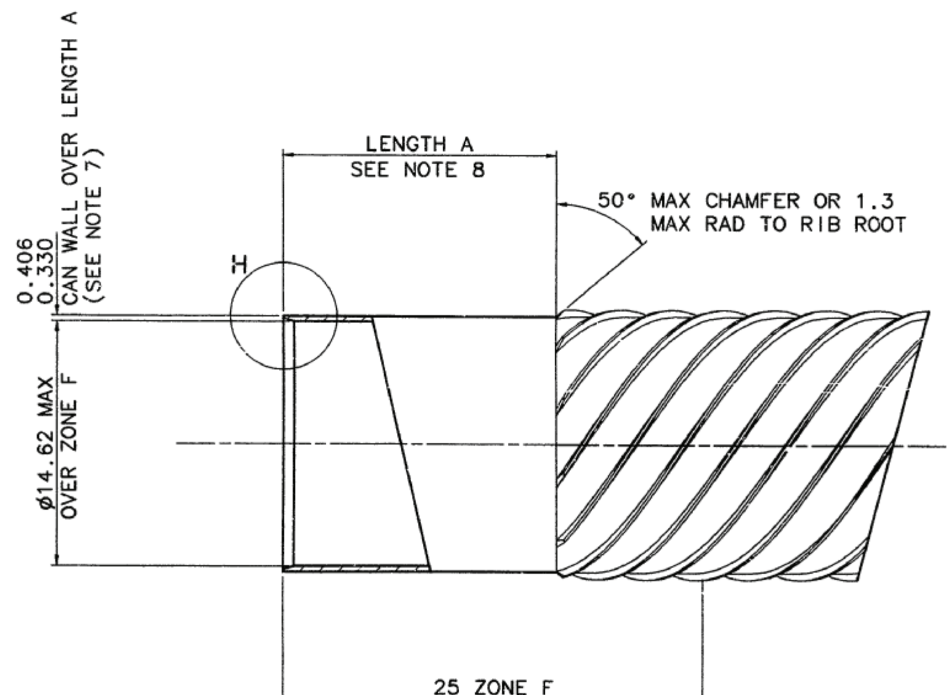
1) "Parallel"



2) "Transverse"

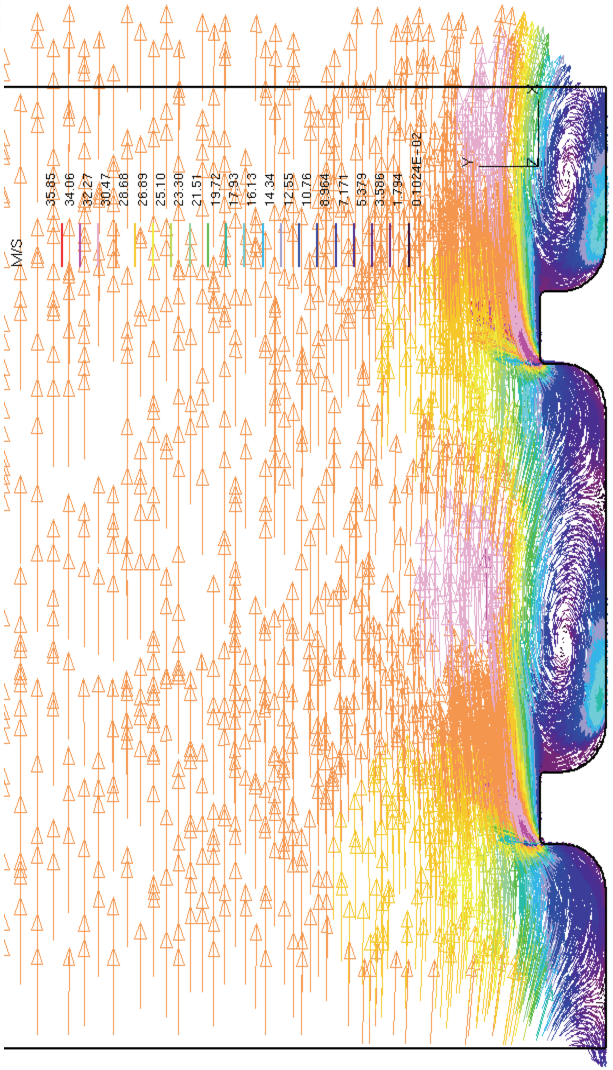


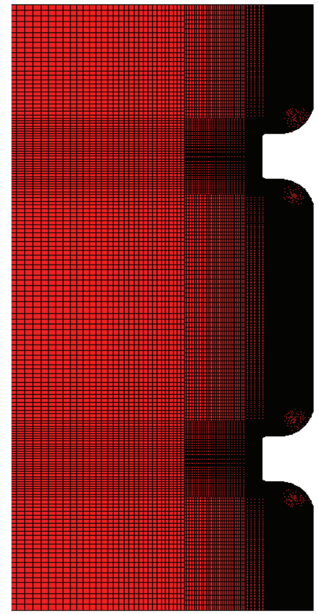
3) "Multi-start" :12 different helixes with different starting points

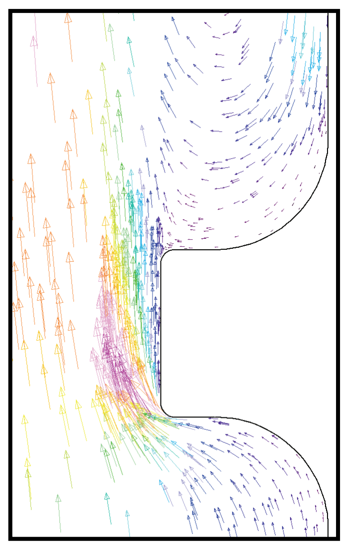


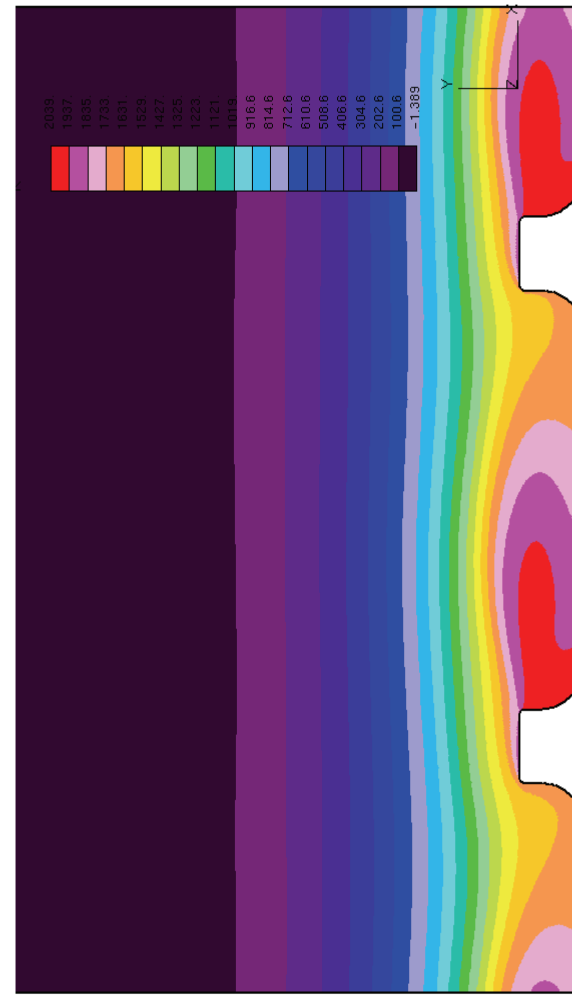
Preliminary Results "Transverse Configuration" (A. Keshmiri)

2D Approach with a Low-Reynolds k-ε model

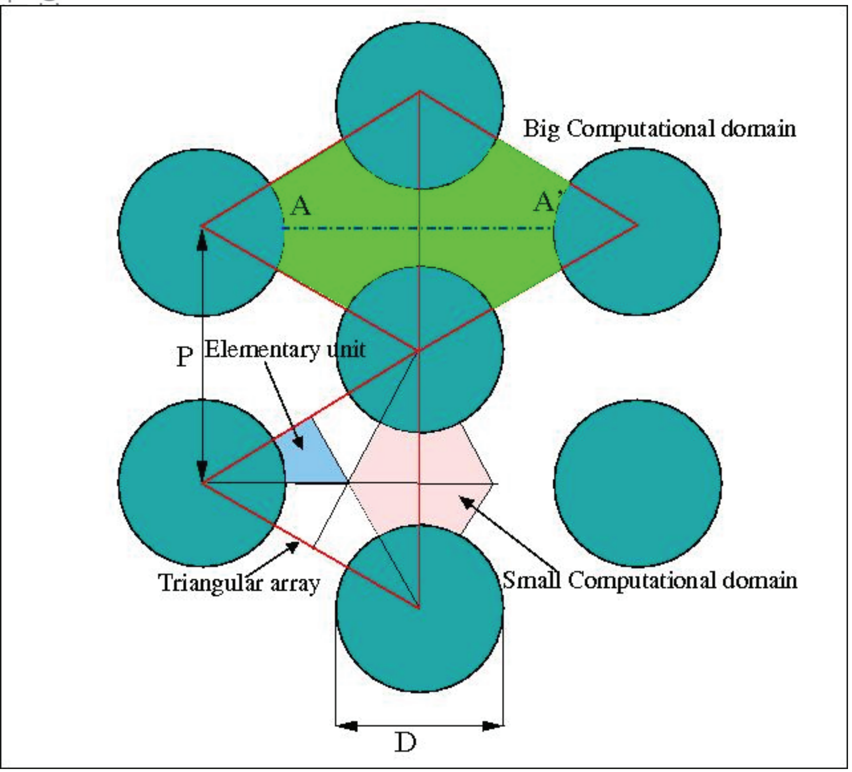


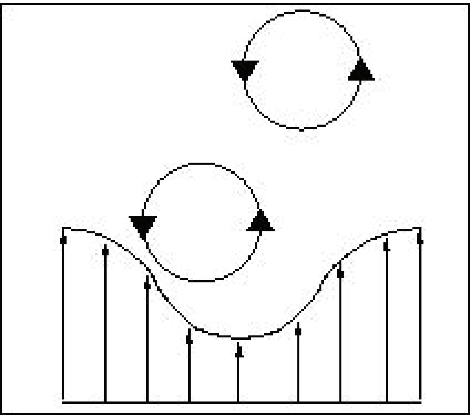






Rod Bundle arranged in a triangular array





- Experimental work:

  I. Secondary flow : *Vonka "Measurement of secondary vortices in Rod Bundle" Nuclear Engineering and Design, Volume 106, Issue 2, 2 February 1988, Pages 191-207*

  II. Flow pulsations: *Krauss, Meyer "Experimental investigation of turbulent transport of momentum and energy in a heated rod bundle", Nuclear Engineering and Design, Volume 180, Issue 3, April 1998, Pages 185-206*

- CFD work (URANS):

  1. *E. Merzari, H. Ninokata, E. **Baglietto** "Numerical simulation of flows in tight-lattice fuel bundles Nuclear Engineering and Design", Volume 238, Issue 7, July 2008, Pages 1703-1719 .*

  2. *D. Chang, S. **Tavoularis** "Simulations of turbulence, heat transfer and mixing across narrow gaps between rod-bundle sub-channels" Nuclear Engineering and Design, Volume 238, Issue 1, January 2008, Pages 109-123*

From II

$$St = \frac{fD}{U_{B,gap}} = 0.93 \quad for \quad \frac{P}{D} = 1.06$$

Rod Bundle: Cases definition

Two different geometrical configuration

1. P/D = 1.06
   - I. LES @ Re = 6000 Mesh size ~ 2 Millions cells with Heat transfer.
     - $0.75<\Delta r+<1.06$
     - $6<r\Delta\theta+<10$
     - $16<\Delta x+<22.5$
   - II. Hybrid @ Re = 6000 Mesh size ~ 0.35 Million cells with Heat transfer
     - $0.8<\Delta r+<1.3$
     - $15<r\Delta\theta+<20$
     - $40<\Delta x+<60$
   - III. Hybrid @ Re = 39000 Mesh size ~ 0.9 Million cells no Heat transfer
     - $0.8<\Delta r+<1.2$
     - $20<r\Delta\theta+<25$
     - $50<\Delta x+<70$
2. P/D = 1.15
   - I. LES @ Re = 6000 Mesh size ~ 1.4 Million cells no Heat transfer
     - $0.8<\Delta r+<1.1$
     - $6.5<r\Delta\theta+<10$
     - $16<\Delta x+<22.5$

All the domains have a stream-wise length equal to 12 times the hydraulic diameter

RANS-LES coupling (1) (J.C. Uribe)

The Hybrid RANS-LES method is following a usual LES decomposition in large scale and sub-grid part:

$$u_j = \underline{\overline{u_j}} + u'_j$$

The anisotropic part of the residual stress tensor and residual heat flux can be decomposed following a Schumann decomposition:

$$\begin{cases} \tau^r_{ij} = \overbrace{-2\nu_r \mathcal{F}_b \left(\overline{S_{ij}} - \langle \overline{S_{ij}} \rangle\right)}^{Locally\,Isotropic} \overbrace{-2\nu_a (1-\mathcal{F}_b) \langle \overline{S_{ij}} \rangle}^{Inhomogeneous} \\ \sigma_j = -\mathcal{F}_b \kappa_r \frac{\partial}{\partial x_j}\left(\overline{T} - \langle \overline{T} \rangle\right) - (1-\mathcal{F}_b)\kappa_a \frac{\partial \langle \overline{T} \rangle}{\partial x_j} \end{cases}$$

$$\nu_r = (C_s \Delta)^2 \sqrt{2 s'_{ij} s'_{ij}}$$

Sub- grid viscosity

$$T = \max\left(\frac{k}{\varepsilon}, C_T \sqrt{\frac{\nu}{\varepsilon}}\right)$$

$$\nu_a = C_\mu \varphi k T$$

RANS viscosity computed from the mean velocity field $(\varphi = \overline{v^2}/k)$

For the eddy conductivity a simply turbulent Prandtl number analogy is used

$$\begin{cases} \kappa_r = \frac{\nu_r}{Pr_t} \\ \kappa_a = \frac{\nu_a}{Pr_t} \end{cases}$$

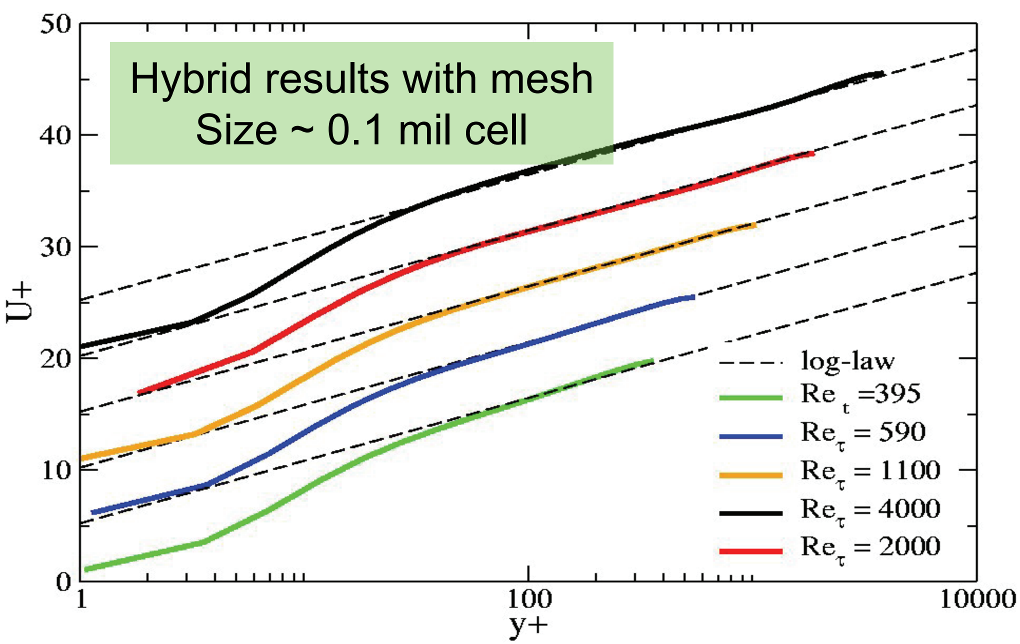
RANS-LES coupling (2) (J. C. Uribe)

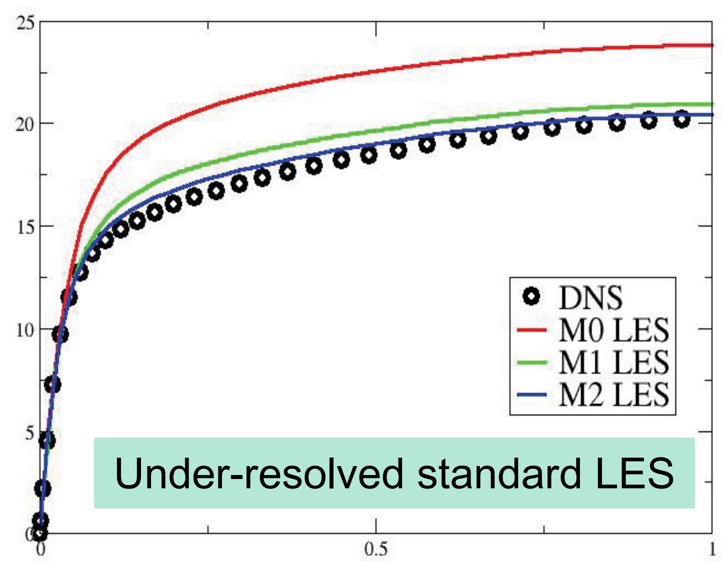
$$\mathcal{F}_b = \tanh\left(C_l \frac{L_t}{\Delta}\right)^n$$ The merging between the two velocity fields is done through a blending function to obtain a smooth transition

$$L_t = \varphi k^{3/2}/\varepsilon$$ Turbulent RANS length scale computed with a relaxation model based on $\overline{v^2} - f$

$$\Delta = 2Vol^{1/3}$$ Filter width

$$C_l = 1.5$$
$$n = 1$$
Empirical constants computed in order to match the stress profile for channel flow @ Re = 395





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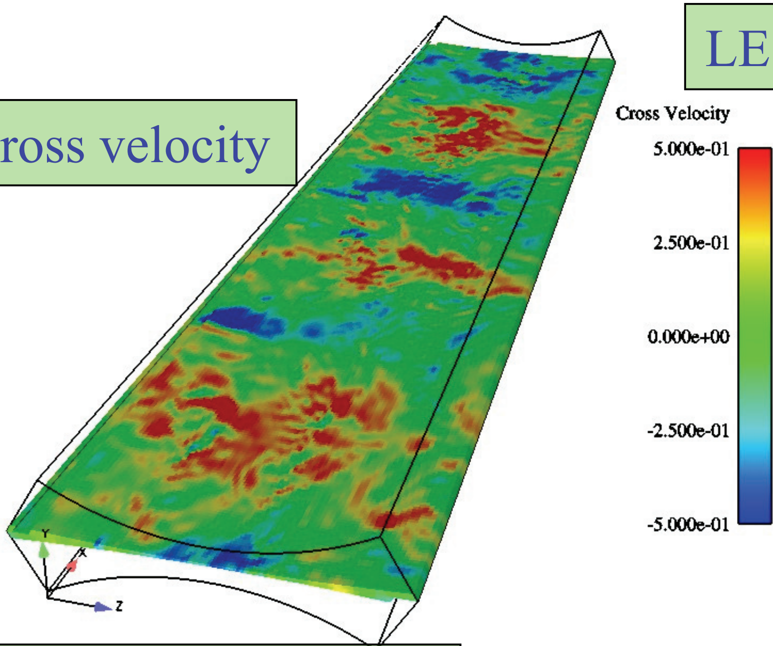
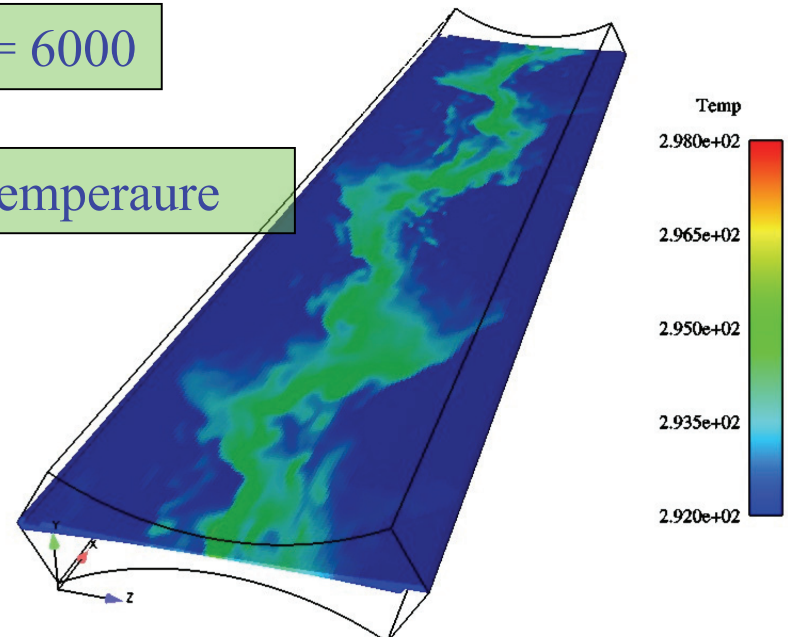
Results: Flow Pulsation in the mid-plane

LES @ Re = 6000

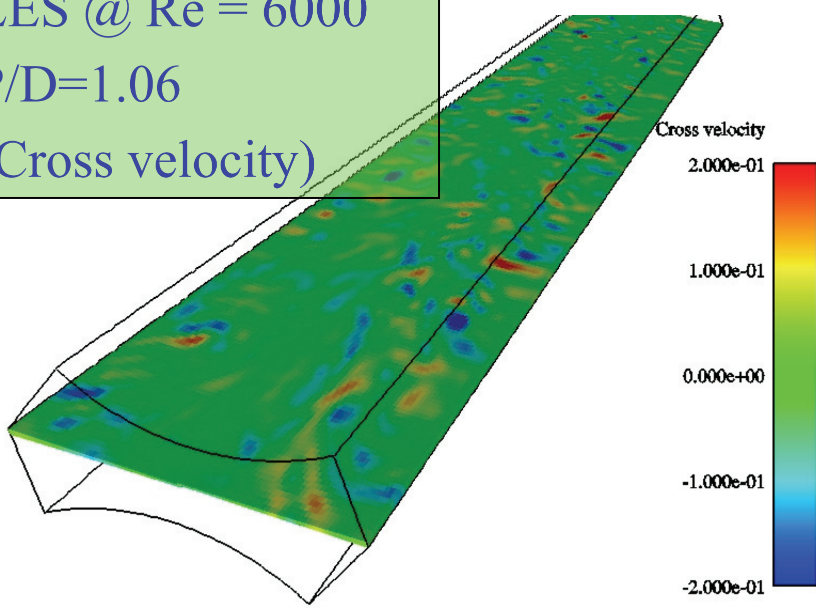
Cross velocity



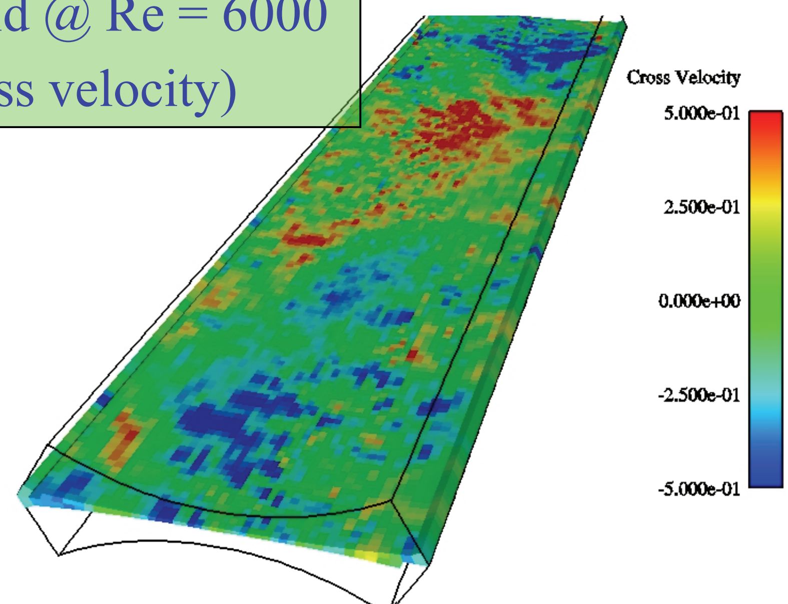
Temperaure



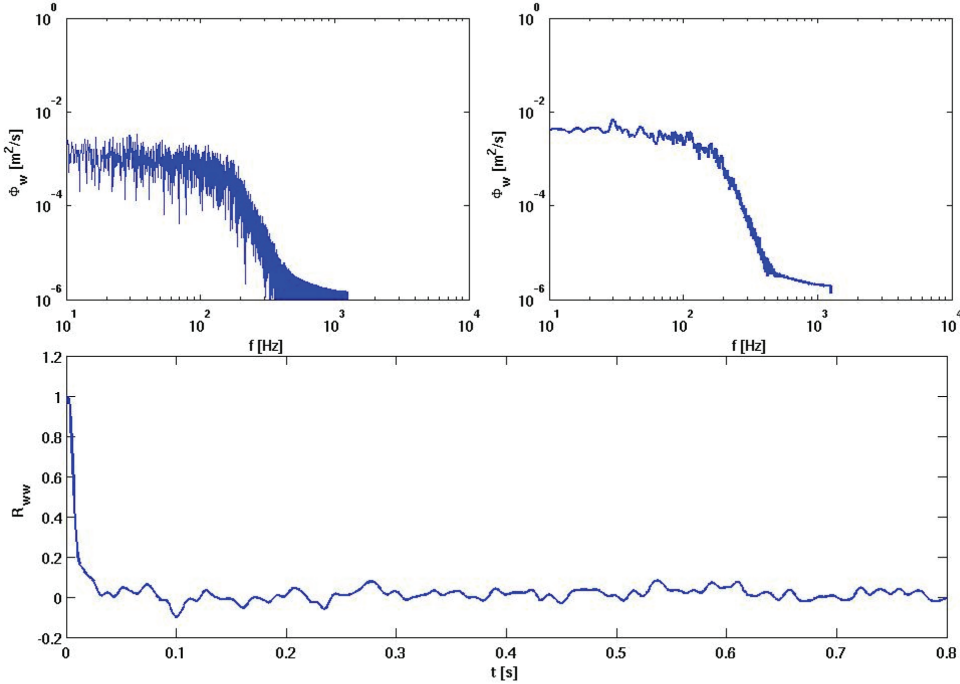
LES @ Re = 6000
P/D=1.06
(Cross velocity)



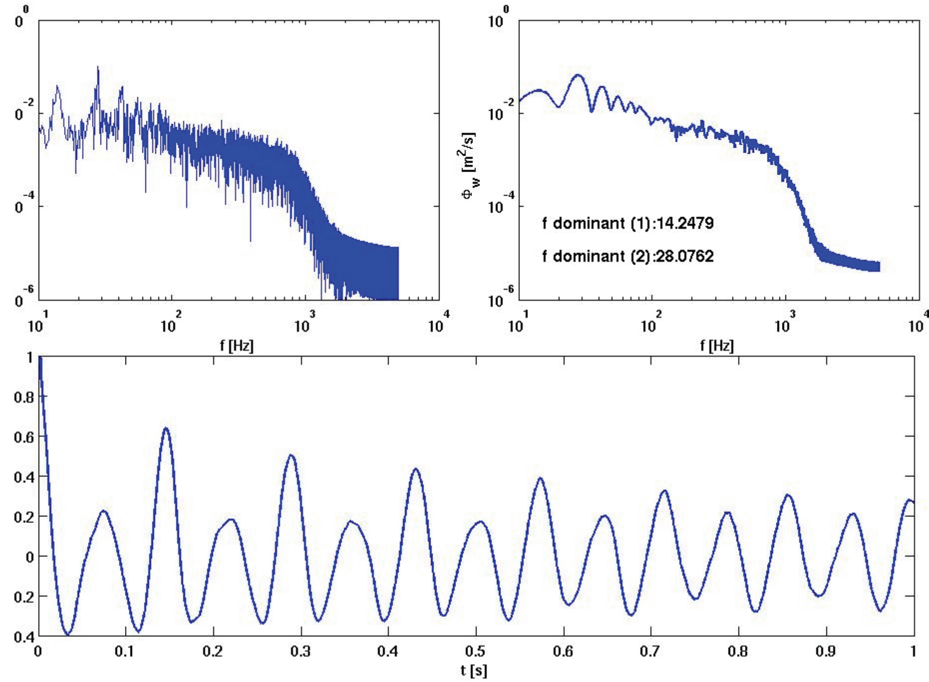
Hybid @ Re = 6000
(Cross velocity)



Power spectra azimuthal velocity

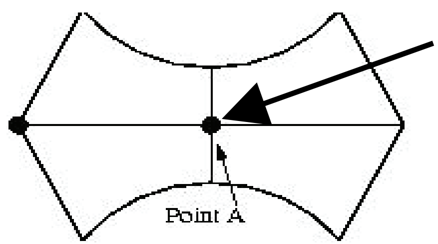


P/D=1.15



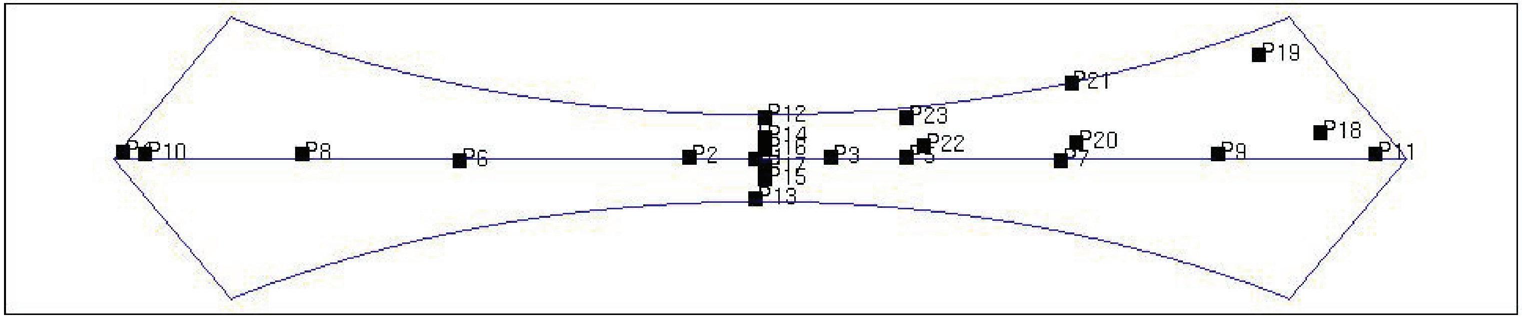
P/D=1.06

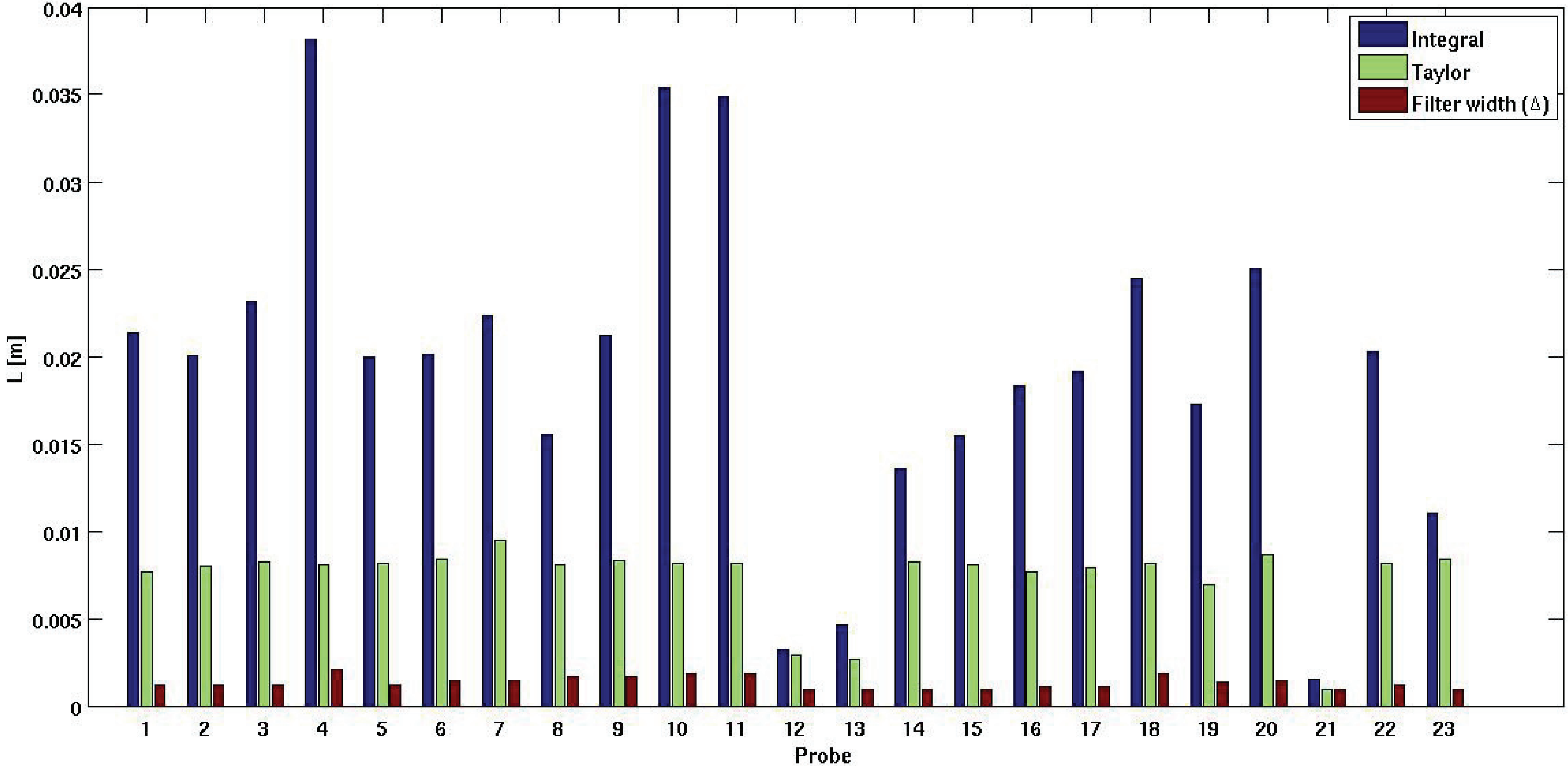
Point A



	LES6K	LESWPD	HYB6K	HYB39K	EXP
$St = fD / U_{B,gap}$	0.98-1.96	/	0.91-1.85	0.92-1.94	0.93

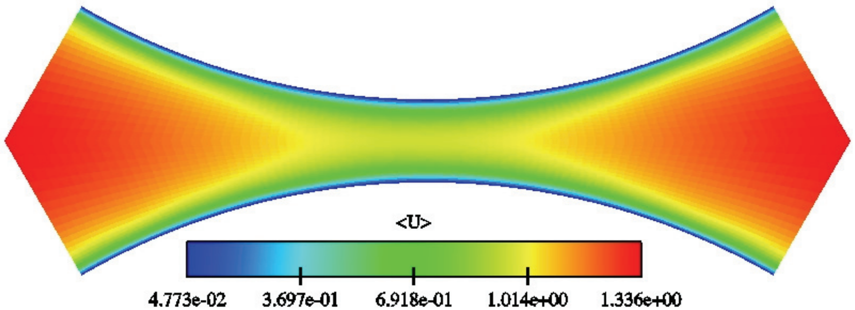
Length scales



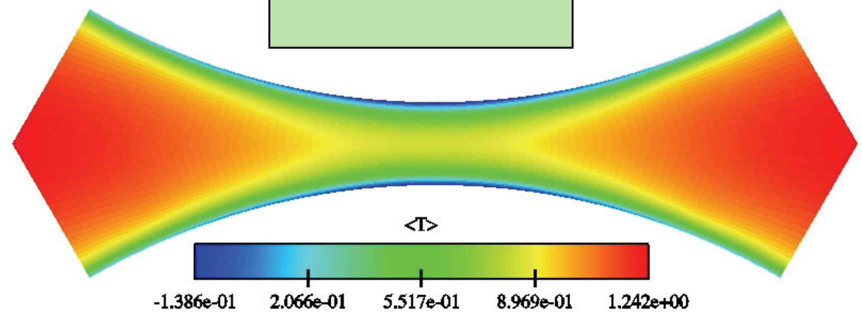


Results: Average Field (LES P/D = 1.06 Re = 6000)

<U>/Ub



$$\frac{T_{w,m} - T}{\left(T_{w,m} - T_b\right)}$$



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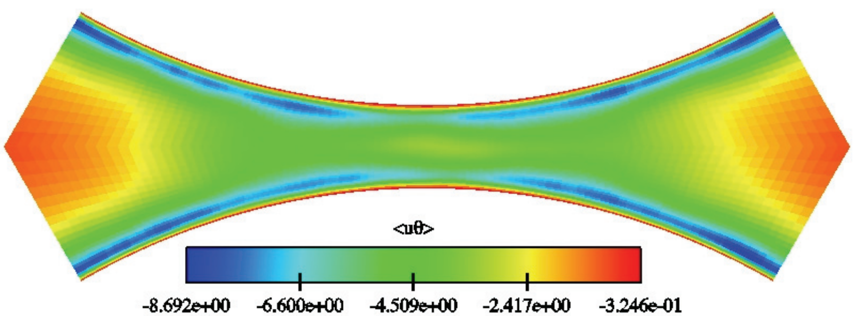

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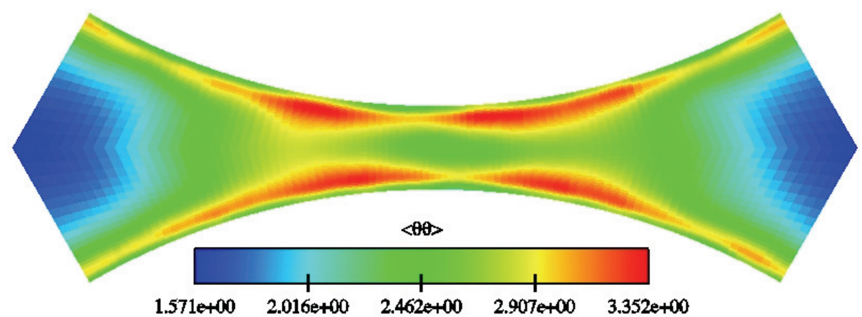

	LES6K	LESWPD	HYB6K	HYB39K	EXP
$\tau_w / 0.5 \rho U_B^2$	0.0086	0.0025	0.0106	0.0104	0.0057
$U_{B,gap} / U_B$	0.75	0.89	0.77	0.83	0.78

Results: Reynolds Stress LES P/D=1.06

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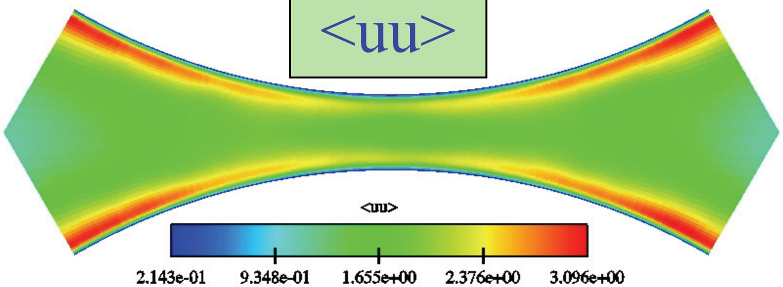

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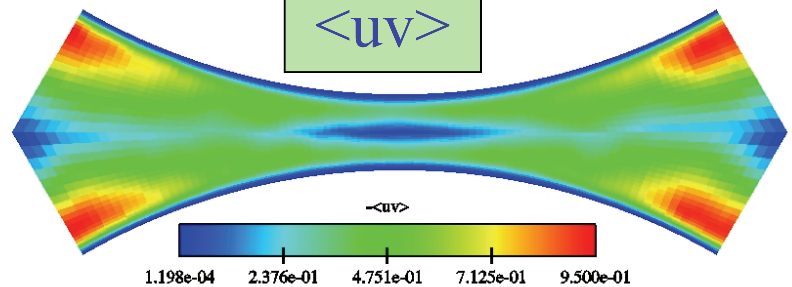

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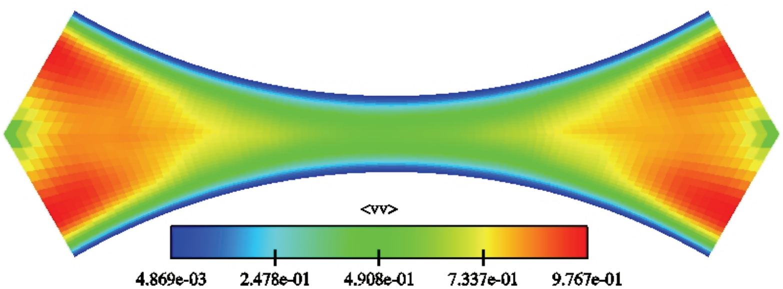

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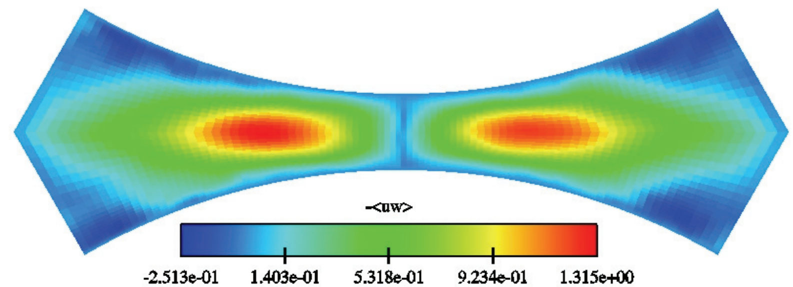

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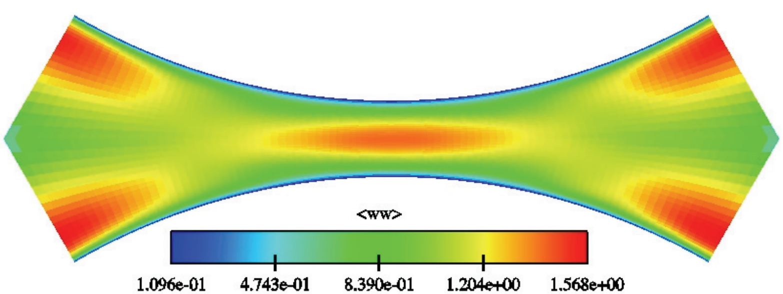

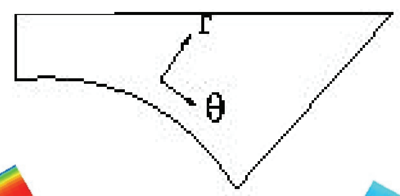

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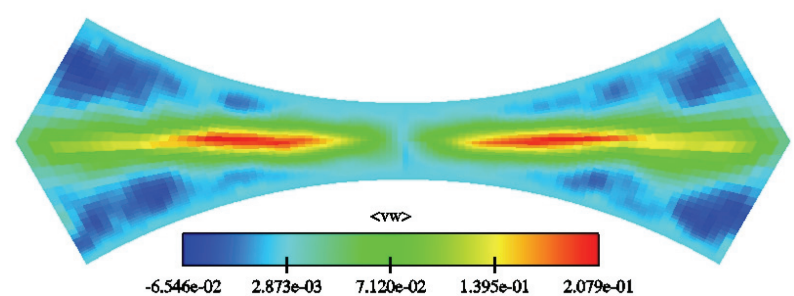

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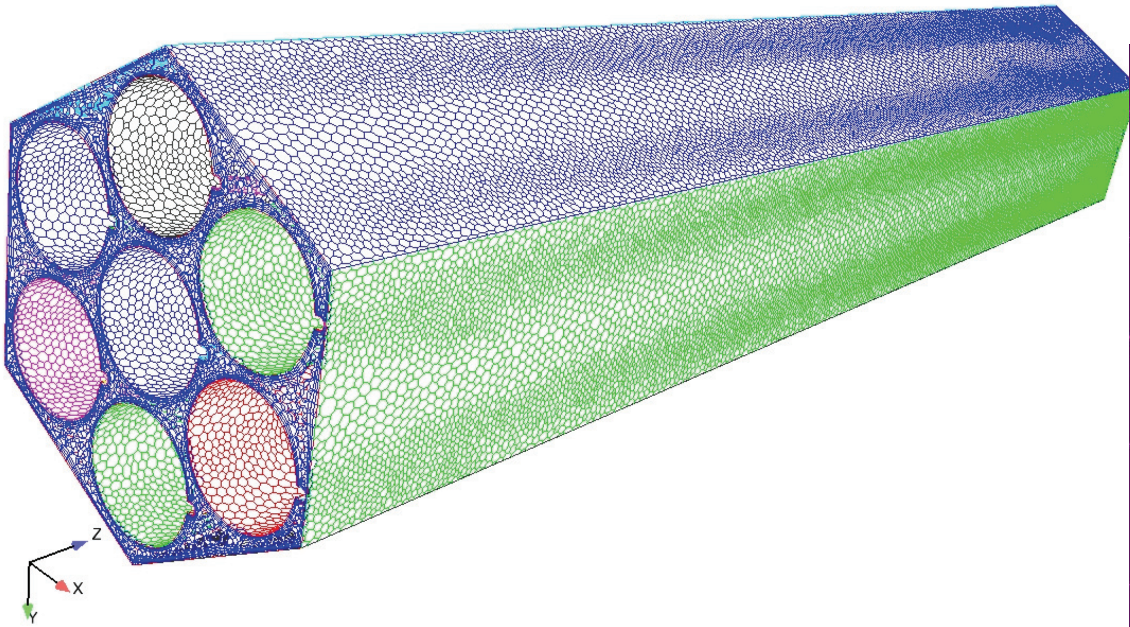
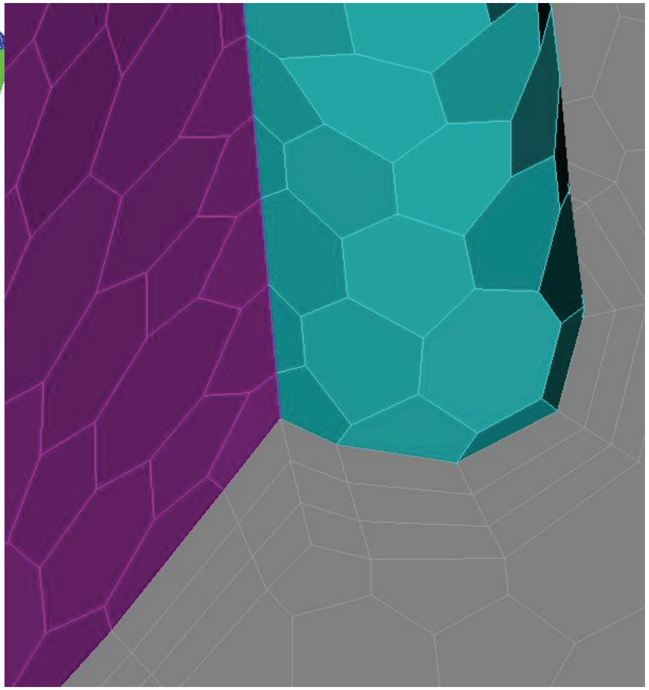
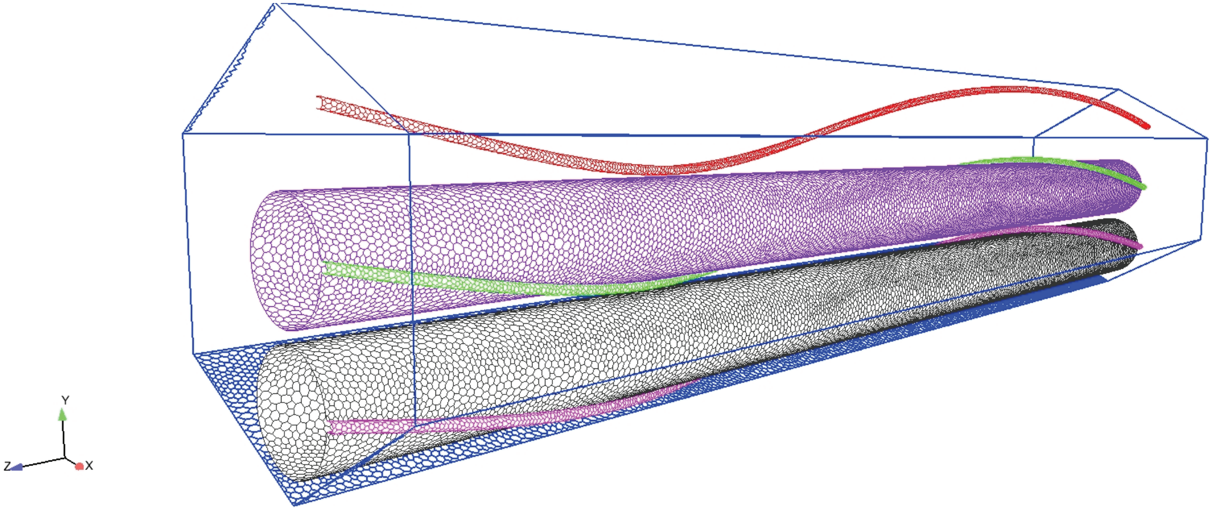
SFR assembly (with C. Penniguel)

Proposal of EdF for the GEN IV reactors







Same geometry presented before with the addition of a wire wrapped around the fuel pin.

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Conclusions.

- **LES**
  - → **Flow Fluctuations detected,**
  - → **Presence of a second dominant frequency has to be verified with bigger domain.**
- **Hybrid**
  - → **Flow pulsations detected and dominant frequency in according with LES**
  - → **Improvement of the blending function for RANS/LES coupling using an elliptic blending (following the work of F. Billard on the α parameter)**
- **KNOO – Heat transfer test cases: expansion of the TWiki portal.**
- **Evaluating possible advantage/disadvantages of polyhedral cells**
- **AGRs: complete 3D study to evaluate possible improvements of the geometrical configuration. (A. Keshmiri)**

Reynolds Stress Hybrid P/D=1.06 Re=39000