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EXPERIMENTAL AND NUMERICAL STUDIES OF TURBULENT FLOW ACROSS IN-LINE TUBE BUNDLES

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Code_Saturne
Users Meeting
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Introduction

The experimental and numerical studies are motivated by the great interest for turbulent flow across tube bundles from power generation industry. Trusted numerical predictions are useful to examine the performance of heat exchangers or safety studies to predict the vibrations caused by fluid-structure interaction or large temperature fluctuations that may eventually lead, in some scenarios, to the thermal stripping. Large Eddy Simulations have shown a strange non-symmetric solution for certain tube spacing (Benhamadouche and Afgan [2,4])

EDF’s open source CFD software ***Code_Saturne*** ** based on the collocated finite volume method has been tested with both, the URANS and DES techniques and 2D and 3D computational domains. For URANS approach: standard κ – ϵ, Menter`s shear stress transport (MSST), Reynolds Stress Model (RSM) and the SST-Cas model recently developed by Revell [1]. For DES technique, the (SST-LES) model has been tested.

Experiment

Figure-1: The wind tunnel

1. **Experimental apparatus:**
   The USTO TE44 closed section wind tunnel is driven by an A.C motor and axial flow fan that forces air around the circuit. The maximum velocity is 60 m/s (Fig.1). Figure-2 illustrated , the new working section made for the present test case with dimensions of L x L=46 mm x 46 mm. This working section includes a set of (7x7) cylinders (Fig.3)

2. **Method:** The pressure distribution around some of the tubes as a function of the azimuthal angle is measured using a multi-tube manometer (Fig.2). The pressure signals are also measured (using the TE81 balance with the software Data Slim) for different angles with a pitch of 15 degree. Figure-4 illustrates the wall pressure distribution for two neighbouring cylinders placed in the centre of the working section.

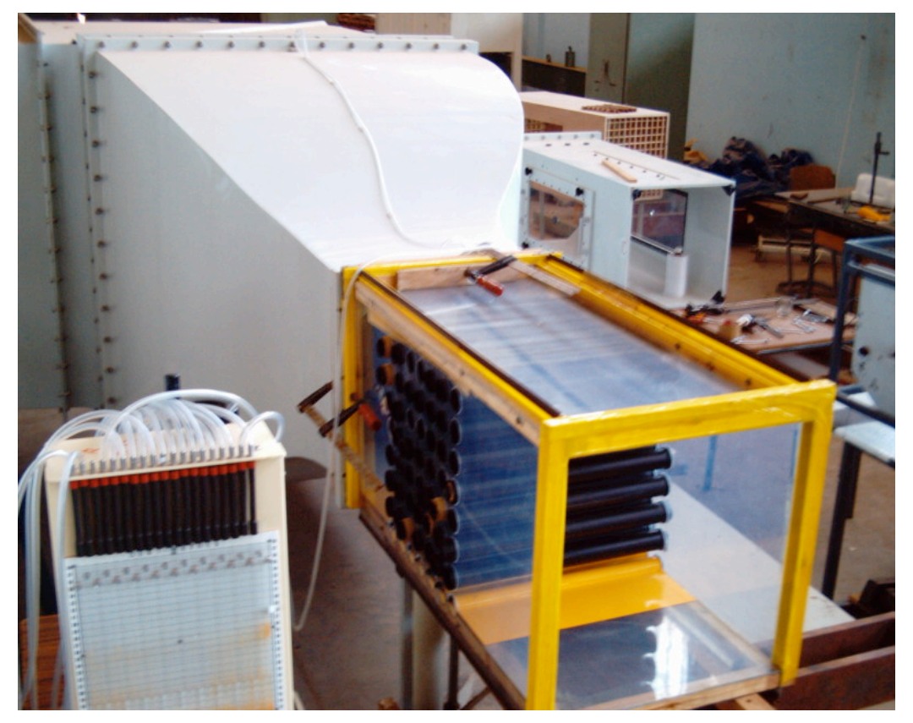


Figure-2: The working section and multi-tube manometer.

3. **Physical parameters:**
   - Reynolds number = 70000 (based on diameter and gap bulk velocity).
   - Static Pressure: P = 1.015 bar, temperature: T = 25 C°
   - Free stream and Gap bulk velocity : U_∞ = 3.1321 *m/s*, U_g = 10.2505 *m/s*
   - Sampling time= 1 second
   - Pitch ratio, P/D=1.44 (P=T=57.6 mm, D=40 mm). (Fig. 4)

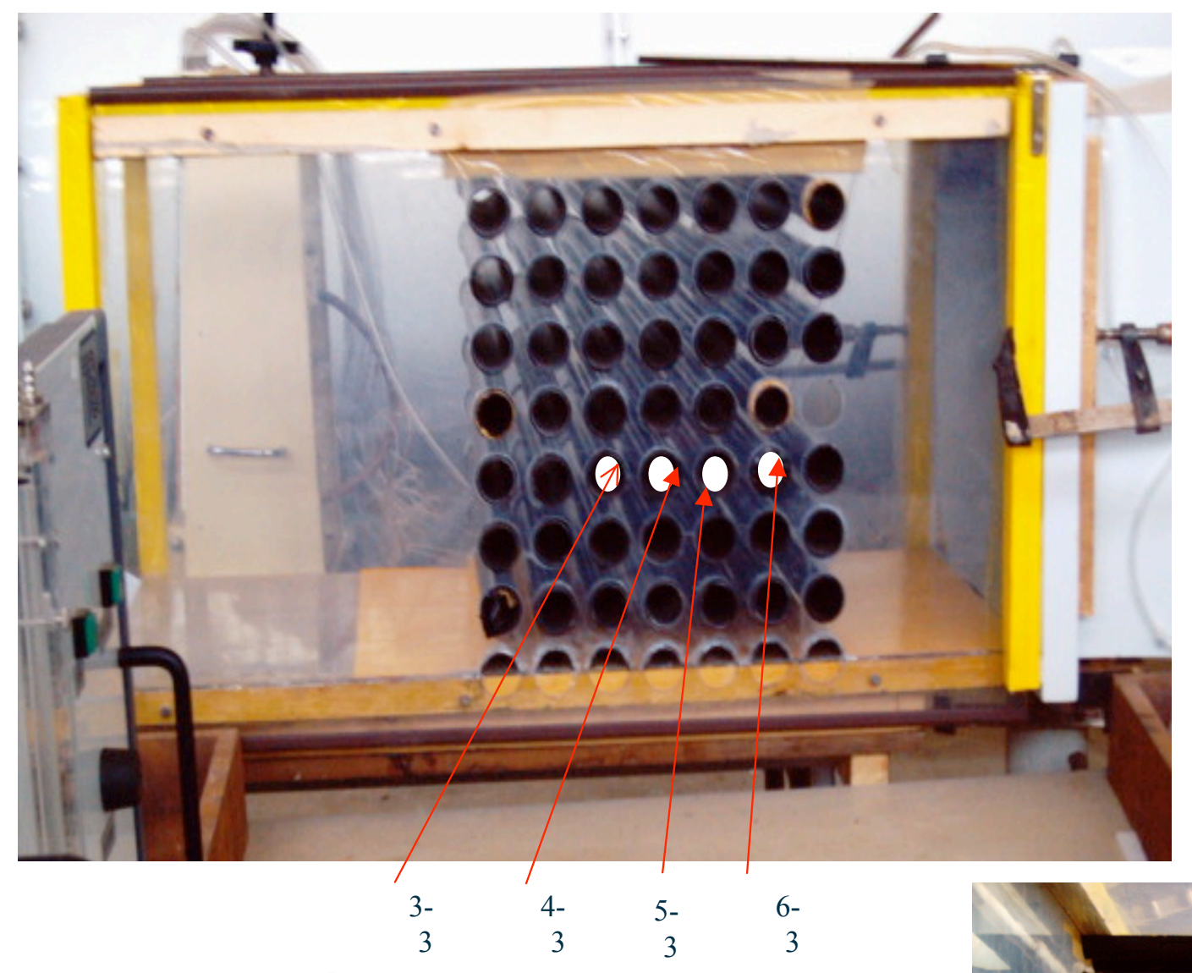
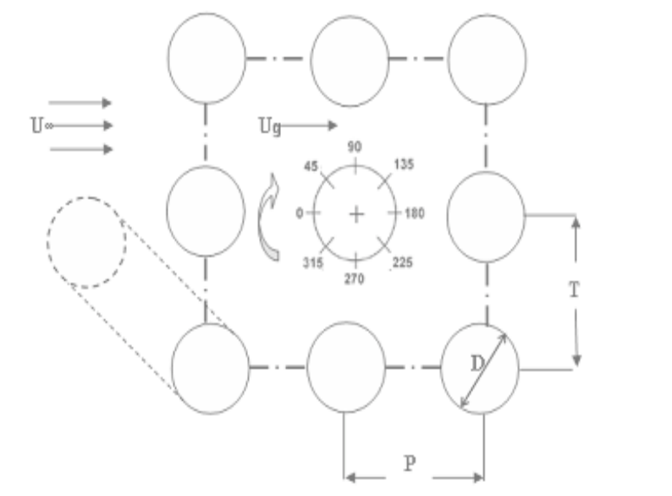
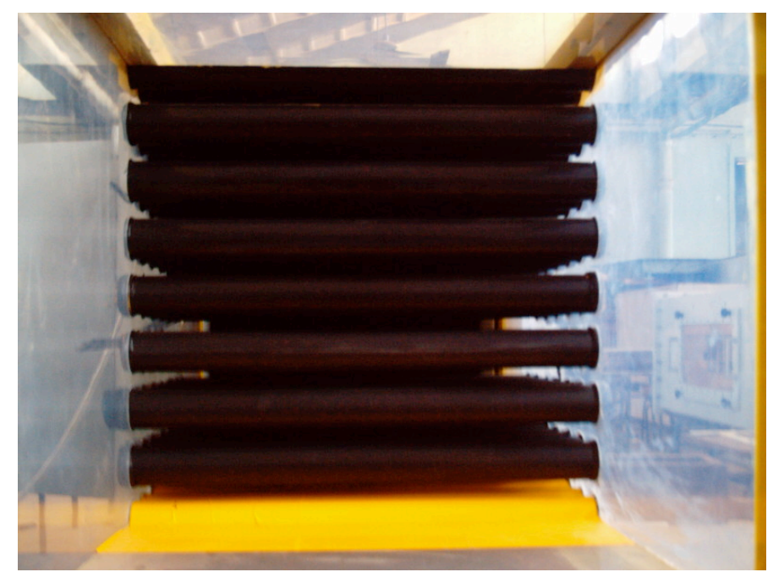


Figure-3: measurement section with the mounted (7x7) inline-tubes





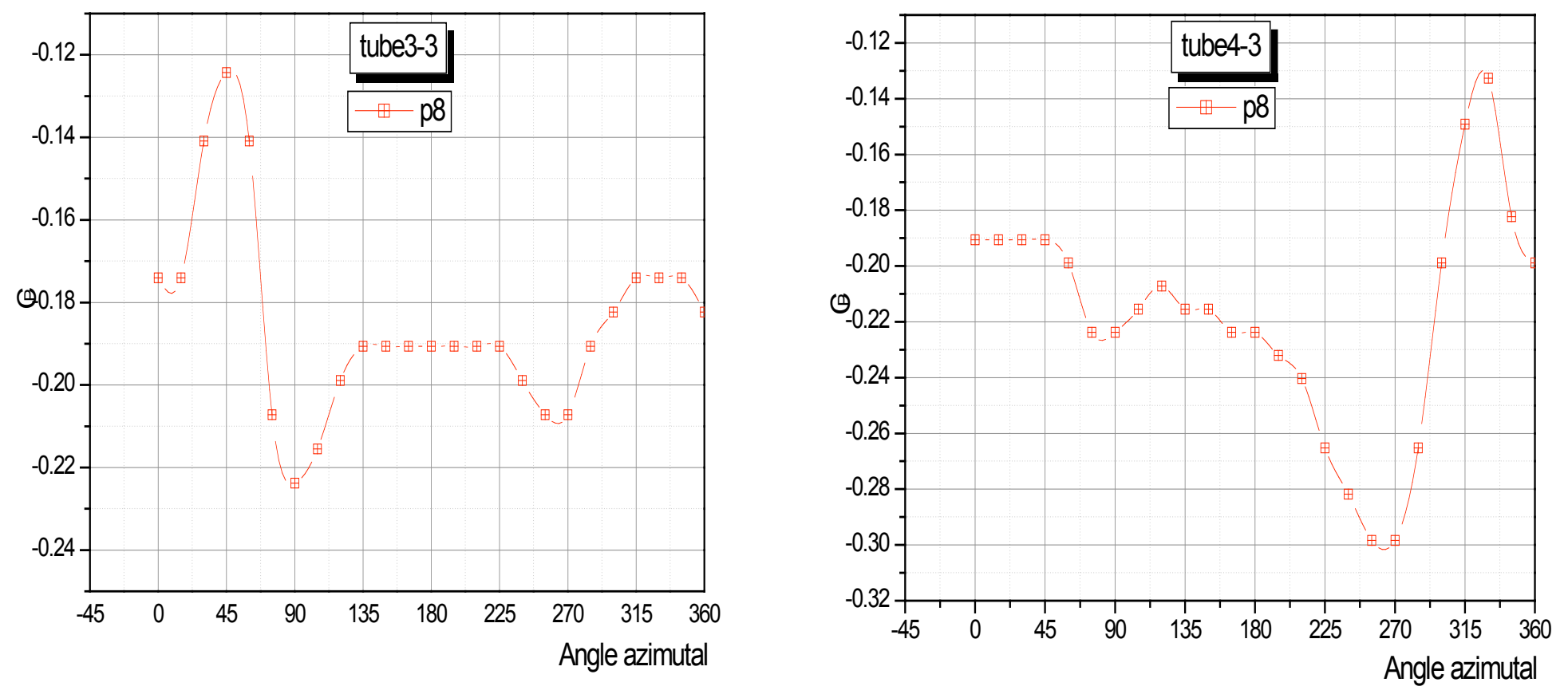


Figure-4: The measured wall pressure distribution for two neighbouring cylinders in the centre of the working section.

Numerical study

The 2D and 3D grids, used for the present computations are presented in figure 5. Figure-6 shows the instantaneous pressure contours in a XY cross sectional as predicted by the different URANS models mentioned above. With exception of the standard k-ϵ model, all the models show a transient and asymmetric behaviour of the flow. The standard k-ϵ model is observed to suppress pressure fluctuations even though the computations are carried out in the transient mode.

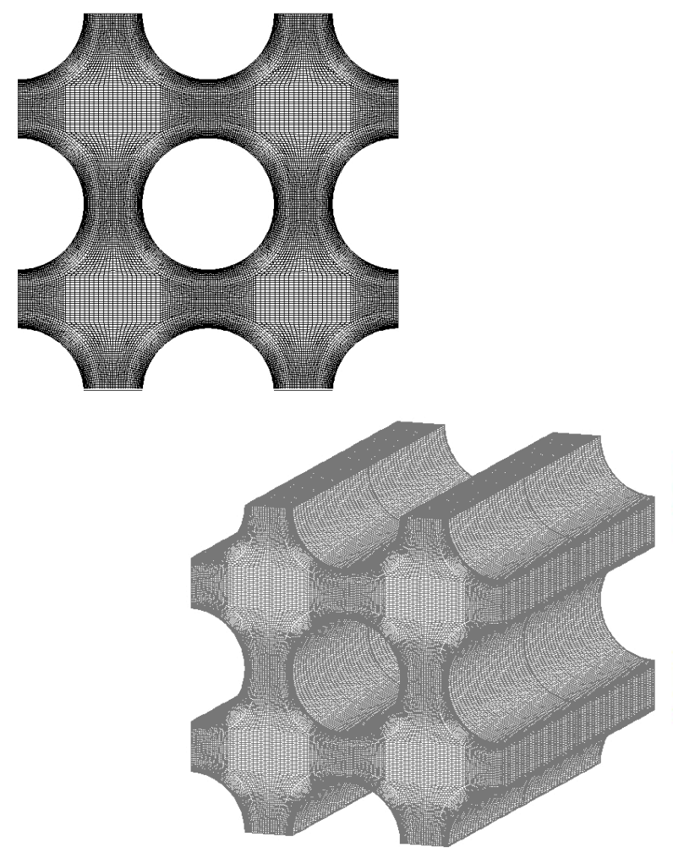


Figure-5: 2D and 3D grids.

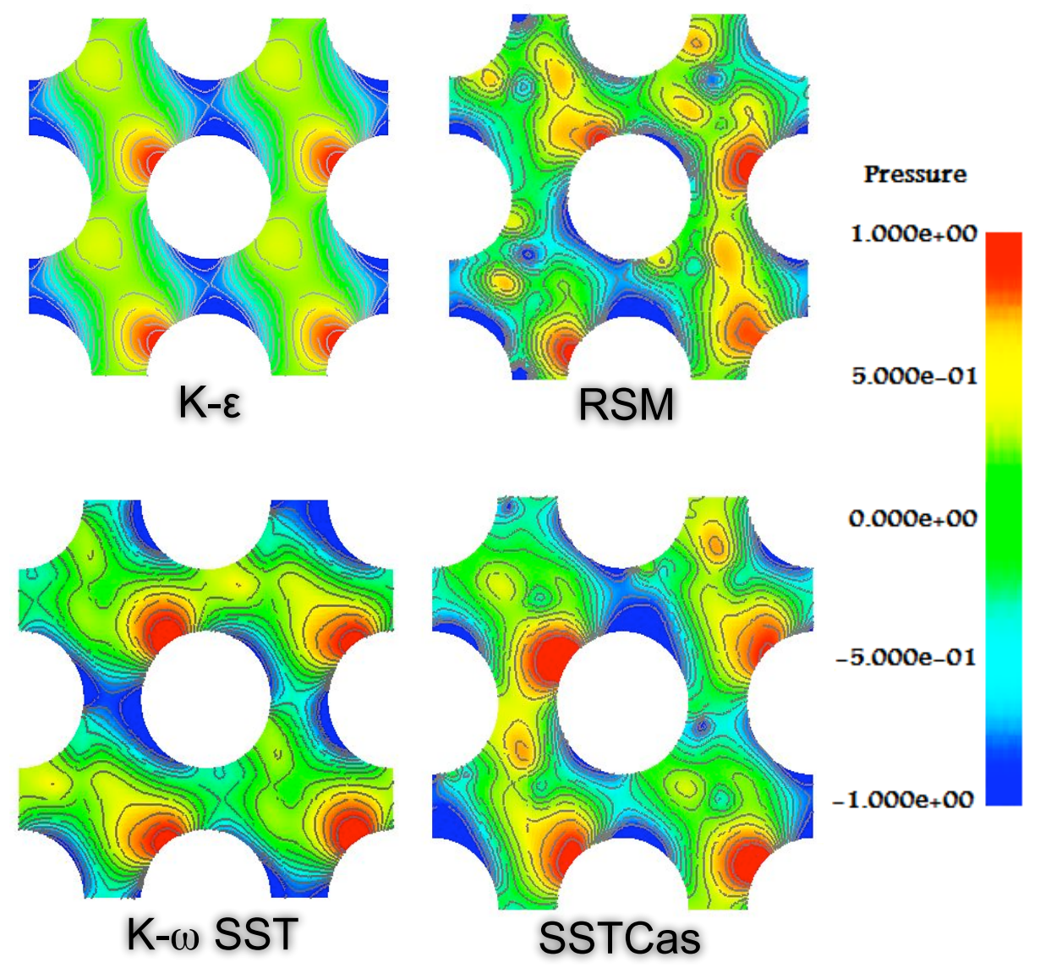


Figure-6: Instantaneous pressure contours in a XY cross sectional view.

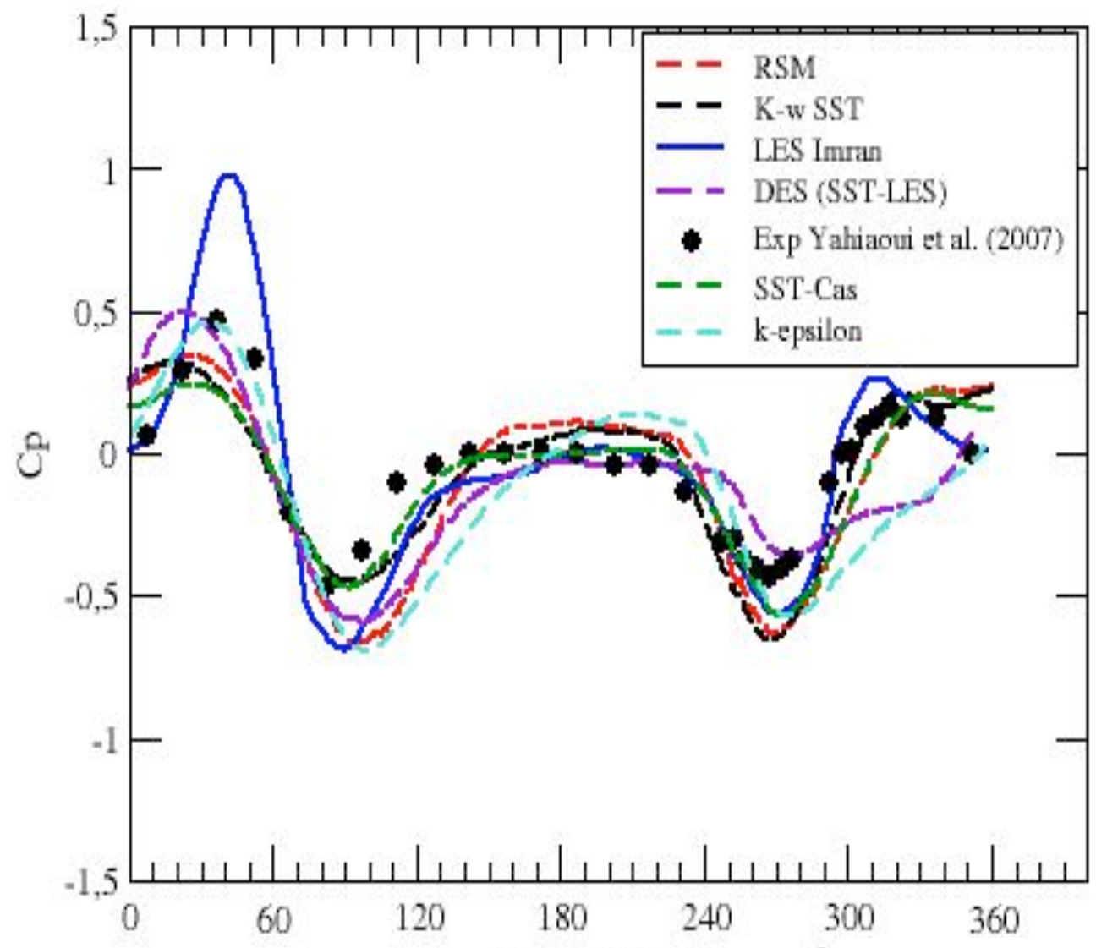


Figure-7: Distribution of normalized pressure coefficient around the central tube.

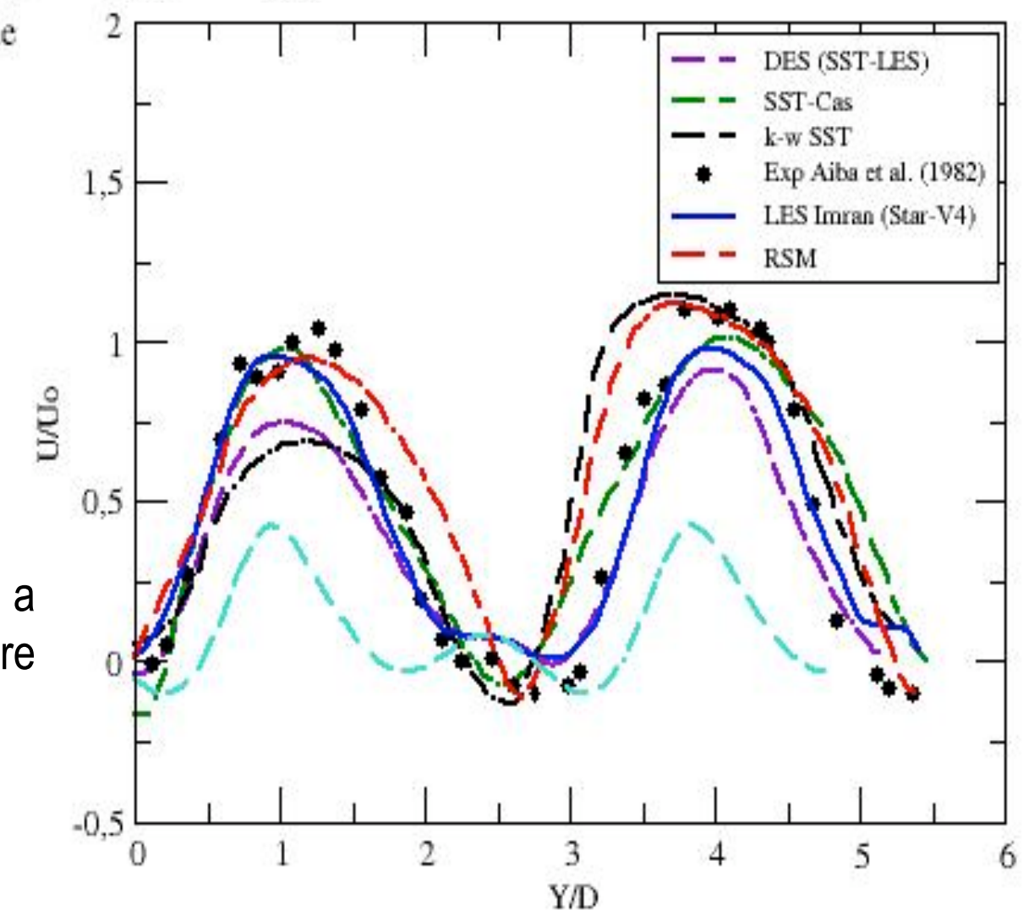


Figure-8: 3D mean velocity along a vertical line in the wake of centre tube at x=4.33.

Figure-7 shows the evolution of normalized pressure coefficient around the central tube for gap ratio of 1.44. The effect of flow deflection is observed in term of stagnation pressure region located somewhere around 45 degree from the flow direction in good agreement with the experimental data [5] and LES results obtained from previous study conducted by Imran Afgan [2,4]. The minimum pressure is located at around 90 degree because of a separation of a shear layer and a recirculation region.

Figure-8 shows the 3D mean velocity along a vertical line in the wake of tube at X= 4.33. URANS models capture a maximum peaks of velocity around U/Uo= 1 m/s far from the wall in free stream flow. The minimum value is around zero close to the wall and in the gap space where the viscous forces are localized. All the curves show the same trend but only the experiment [3], LES and DES results are observed to follow the particular velocity variation in the gap space region (2 <Y/D<3.5). The velocity maximum seems to be under-predicted by the DES approach which maybe related to the coarsening of the used grid in that region.

Figure-9 shows fluctuating pressure and its power spectral density (PSD) at a location of probe 6. The pressure spectra reveal one clear peak around the frequency 45Hz (St=0.84).

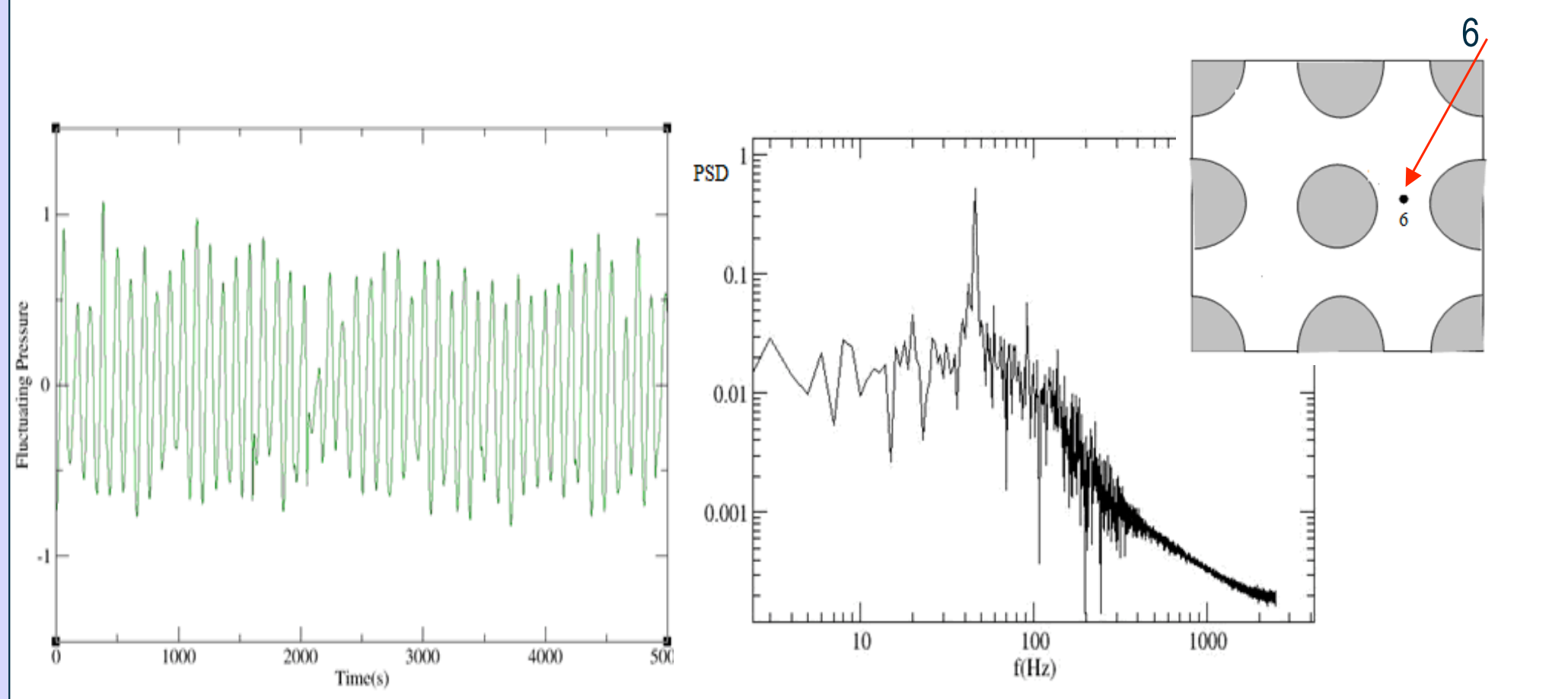


Figure-9: Pressure’s signal and its PSD at a location of probe 6.

Figure-10 shows instantaneous Q iso-surfaces obtained from the DES (SST-LES) results. A large number of worm-type of vortices are observed in the centre of domain. These structures are observed to originate at the cylinders walls and elongate in the same direction as the across flow.

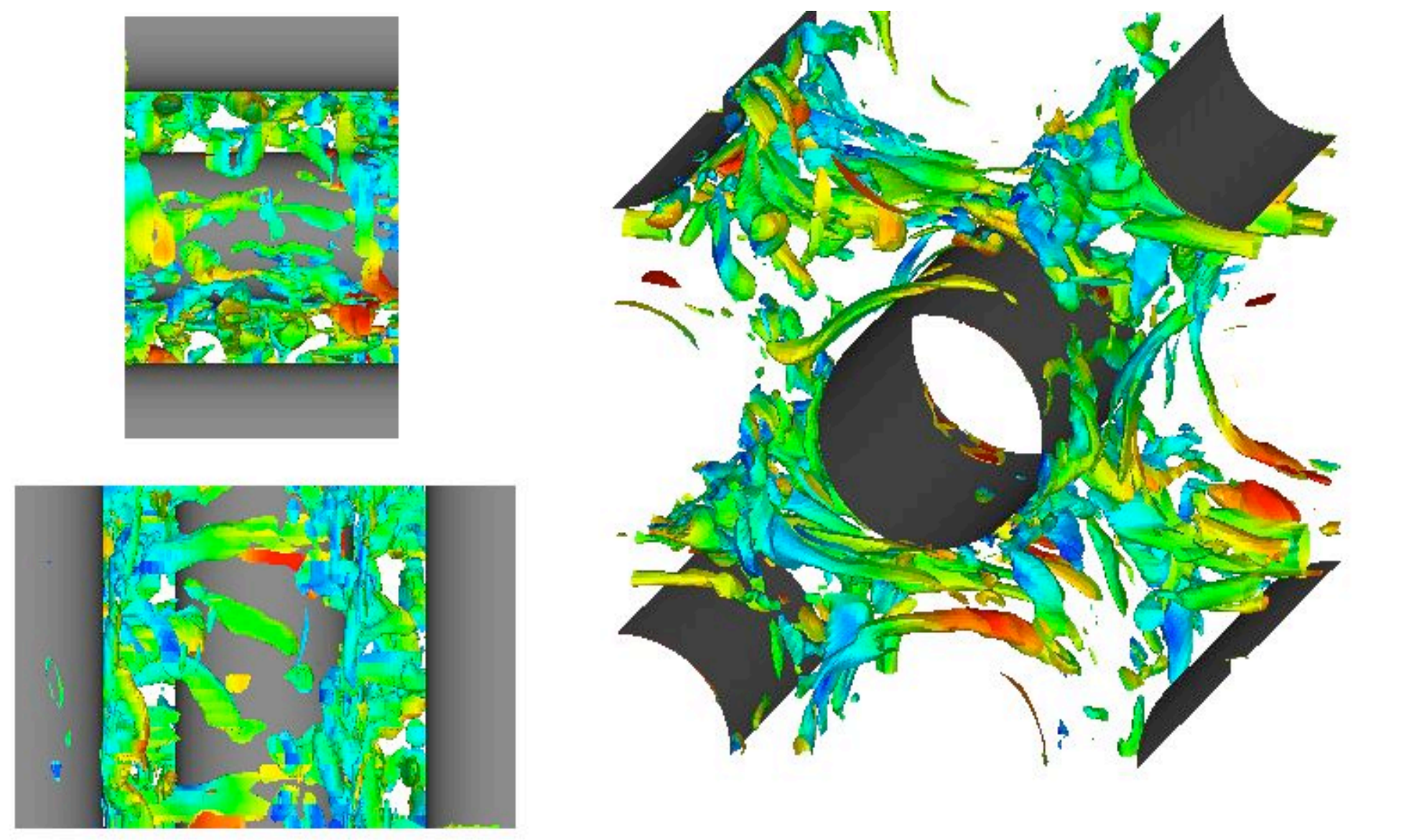


Figure-10: instantaneous Q Iso-surfaces, present DES results

Conclusions

- The flow across in-line tube bundles is found to be asymmetric and transient.
- URANS technique in 3D with k-ω SST, RSM and SST-*Cas* models and the DES (SST-LES) approach are able to capture the transient flow behaviour, while the k-ϵ model suppresses all flow fluctuations.
- Stagnation point is located somewhere around 45 degree. It agrees with LES of Afgan and experiments recently carried out at Oran’s University.
- From PSD results applied to pressure and velocity signals, show a peak around 45 Hz (St=0.84).
- By drawing the structure paramete Q, fine 3D structures in the gap space between cylinders, similar to LES. There are more streamwise and spanwise structures for SST-Cas and DES (SST-LES) than the other URANS models.
- Two recirculations behind a centre tube are observed. One is larger than the other. The large one is located in the bottom and a small one is on the top. Shear stress in bottom is higher than on top of tube.
- Finally, good quantitative and qualitative agreement with the experimental results shows the ability of the present approach (Unsteady RANS) to correctly reproduce the essential physics associated with massively separated flow.

References

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[5] Yahiaoui, University of USTO, personal communications.
* **EU TEMPUS “COFFEE” Project**, Computation For Fluids & Energy Engineering
http://cfd.me.umist.ac.uk/coffee/
** ***Code_Saturne*** open source CFD software
http://cfd.mace.manchester.ac.uk/twiki/bin/view/Main.SatPortal
http://rd.edf.com/code_saturne

Acknowledgements

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