University of Stuttgart
Institute of Nuclear Technology and Energy Systems

Projekt LESHCTF

Numerical analysis of stratified T-junction mixing flows

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Motivation and Aim

A nuclear power plant (NPP) contains a vast piping network supply coolant to the required locations in order to ensure its safe operation. There are certain locations where the fluids at significant temperature differences are mixed to control the resulting outflow temperature. Such mixing occurs mainly in T-junction piping configurations located in the Residual Heat Removal System (RHRS), Emergency Core Cooling System, Charging lines etc. The mixing results in random thermal fluctuations of varying amplitudes over a wide range of frequencies to be imposed on the piping wall. Depending on the piping geometry, material properties and thermal loading on the structure crack initiation could be expected during any timeframe resulting in high-cycle thermal fatigue (HCTF) damage of piping components. This study compares the T-junction flow mixing between the horizontally and vertically aligned T-junction configurations of the Fluid-Structure Interaction (FSI) facility at the University of Stuttgart.

Numerical and computational details

The Favre-filtered conservation equations of mass, momentum and energy are defined by Equation (1-3):

$$\frac{\partial \bar{\rho}}{\partial t} + \frac{\partial \bar{\rho}\tilde{u}_i}{\partial x_i} = 0 \tag{1}$$

$$\frac{\partial \bar{\rho}\tilde{u}_i}{\partial t} + \frac{\partial \bar{\rho}\tilde{u}_i\tilde{u}_j}{\partial x_j} = -\frac{\partial \bar{p}}{\partial x_j} + \frac{\partial}{\partial x_j}\left[\mu_{eff}\left(\frac{\partial \tilde{u}_i}{\partial x_j} + \frac{\partial \tilde{u}_j}{\partial x_i}\right) - \frac{2}{3}\mu_{eff}\frac{\partial \tilde{u}_k}{\partial x_k}\delta_{ij}\right] + \bar{\rho}g_i \tag{2}$$

$$\frac{\partial \bar{\rho}\tilde{h}}{\partial t} + \frac{\partial \bar{\rho}\tilde{u}_j\tilde{h}}{\partial x_j} = \frac{\partial}{\partial x_j}\left(\alpha_{eff}\frac{\partial \tilde{h}}{\partial x_j}\right) \tag{3}$$

To predict random thermal fluctuations of varying amplitudes over a wide range of frequencies accurately the method of Large-Eddy Simulation (LES) in the numerical simulation code OpenFOAM is used. The turbulent eddy viscosity is modeled by using the WALE subgrid-model. The numerical investigation is based on the wall resolved LES which has been experimentally validated with results of the in-house FSI facility. An illustration of the computational domain and boundary conditions are shown in Fig. 1 and Table 1.

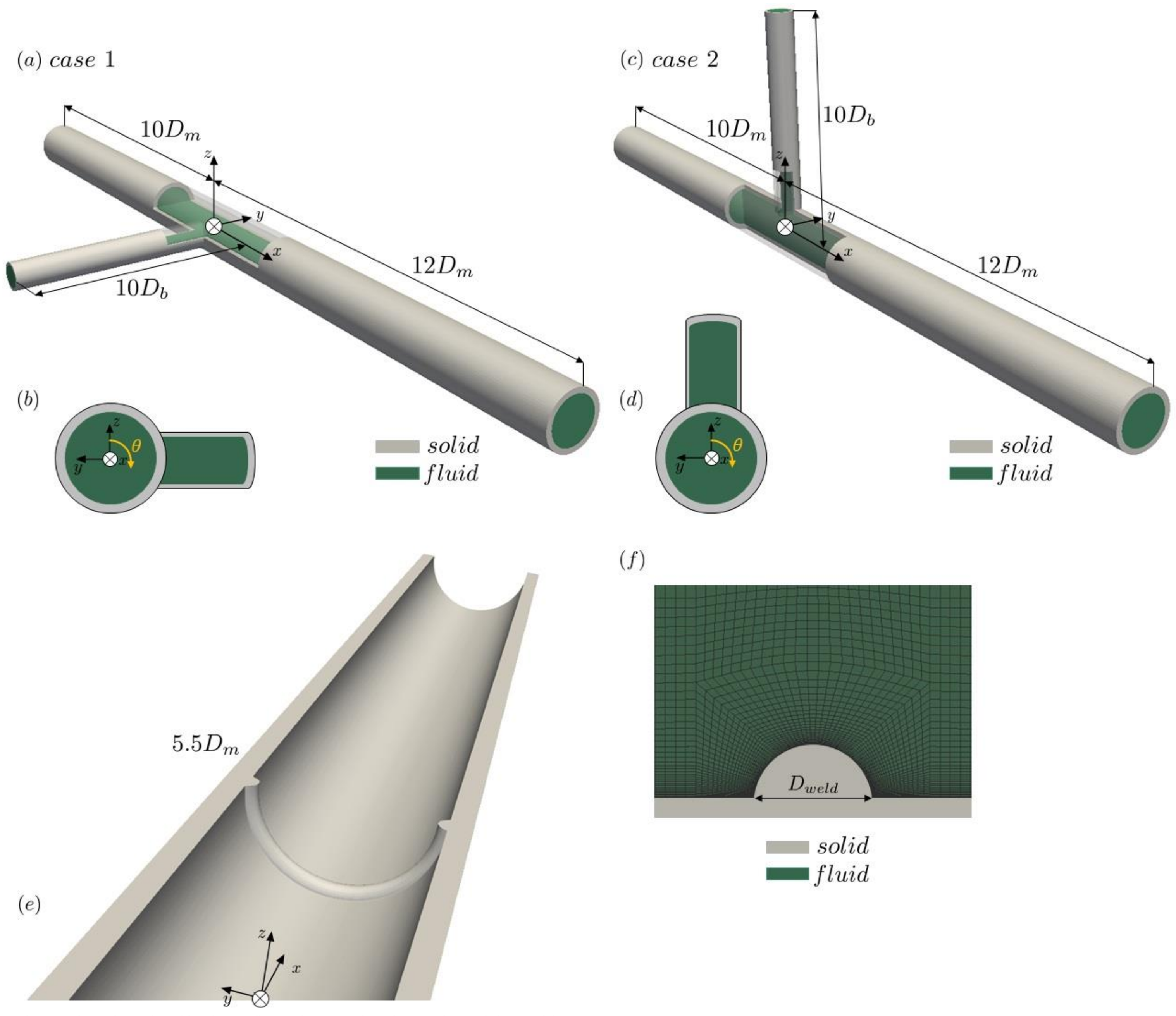
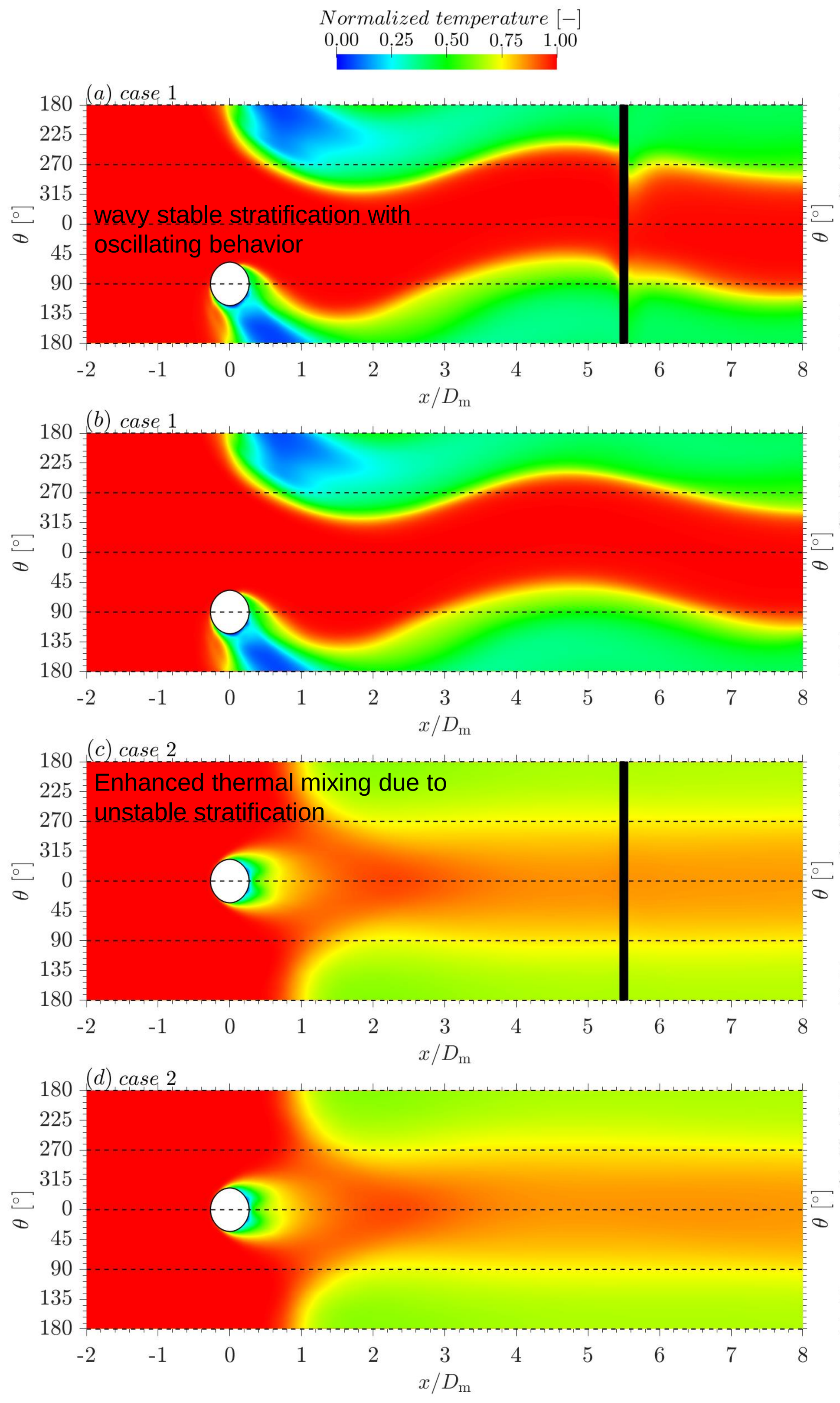


Fig. 1: Flow domain of both configurations and a closer view of the weld seam area

p [bar]	Re_m [−]	Re_b [−]	$\dot{m}_m$ [kg/s]	$\dot{m}_b$ [kg/s]	T_m [K]	T_b [K]	Pr_m [−]	Pr_b [−]
75	78400	6600	0.6	0.2	473.15	293.15	0.9	7

Table 1: Simulation conditions

Results



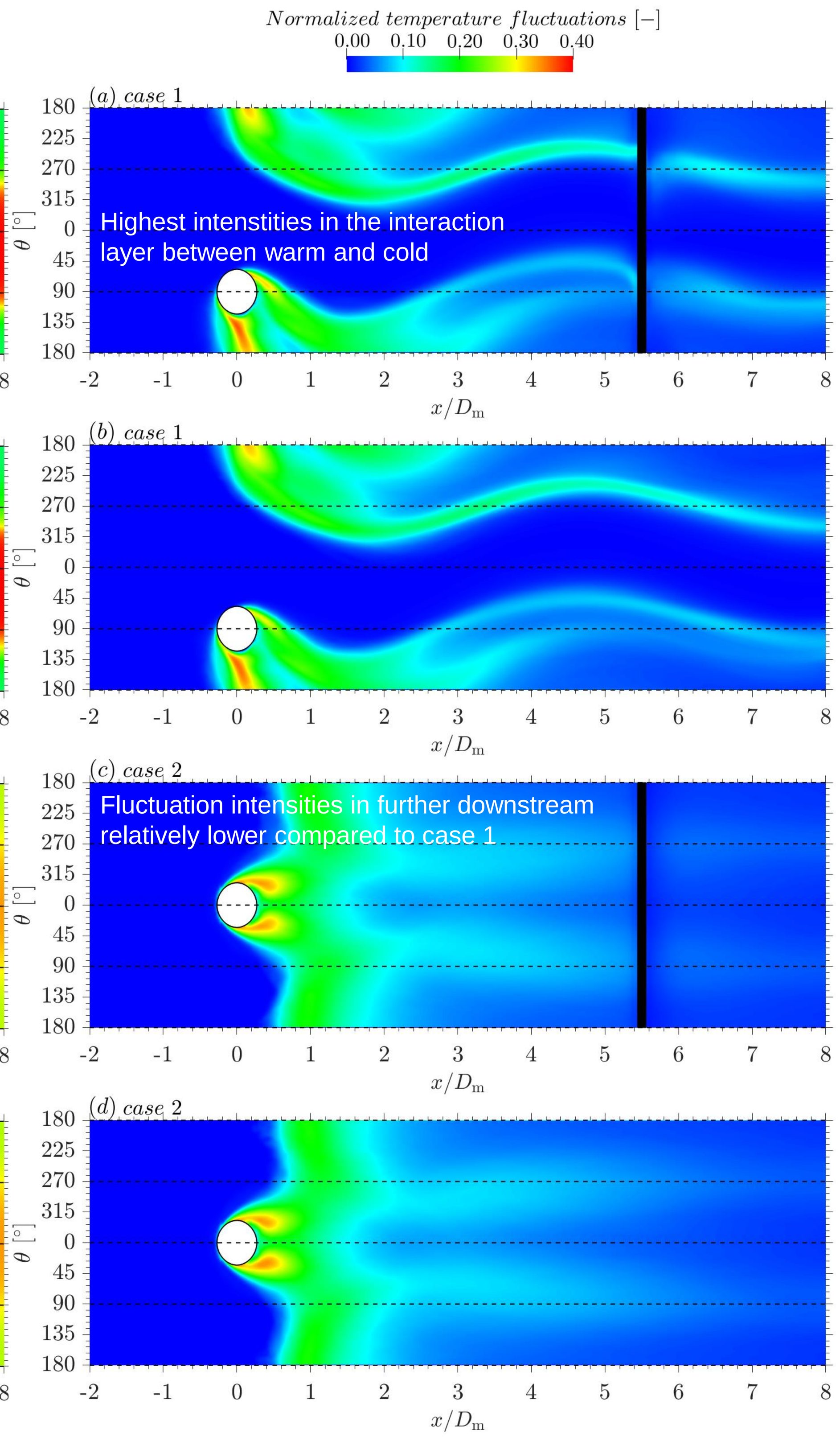


Fig. 2: Circumferential distribution of the mean normalized temperature along the downstream (1 mm from the main pipe wall) with (a, c) and without (b, d) weld seam for both cases

Fig. 3: Circumferential distribution of the mean normalized temperature fluctuations along the downstream (1 mm from the main pipe wall) with (a, c) and without (b, d) weld seam for both cases

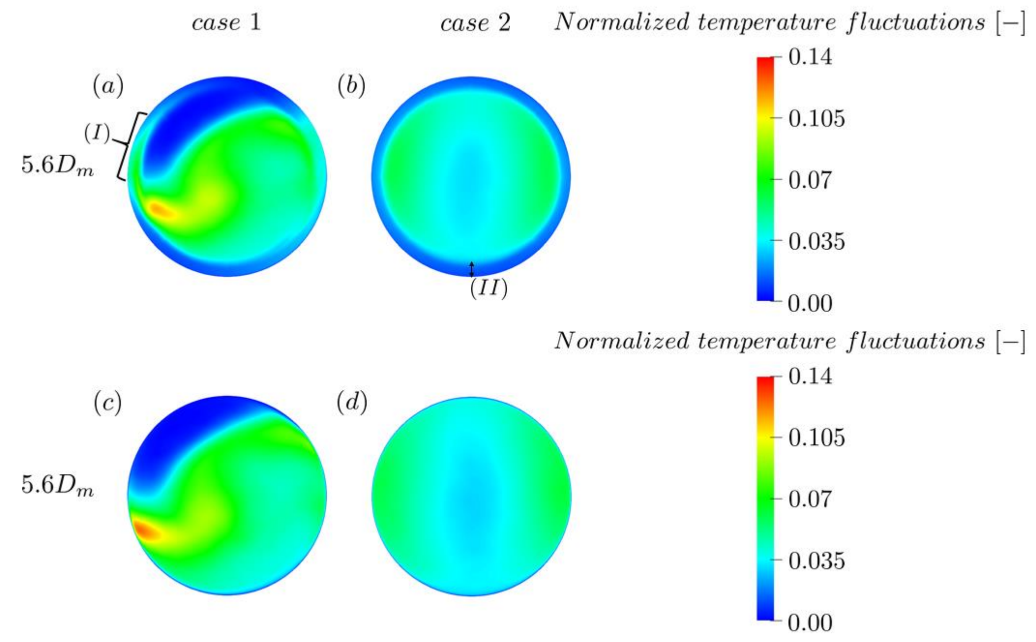


Fig. 4: Normalized temperature fluctuations at x = $5.6D_m$ with (a, b) and without (c, d) weld seam for both cases

The effects of the reduction of the inner diameter on the mixing behavior in case 1 can be seen in Fig. 4 (a, c), where the fluctuation intensity in the near-wall region is rotated and shifted upwards in area (I). In case 2, the thermal fluctuations in the near-wall region (II) are strongly decreased as shown in Fig. 4 (b, d).

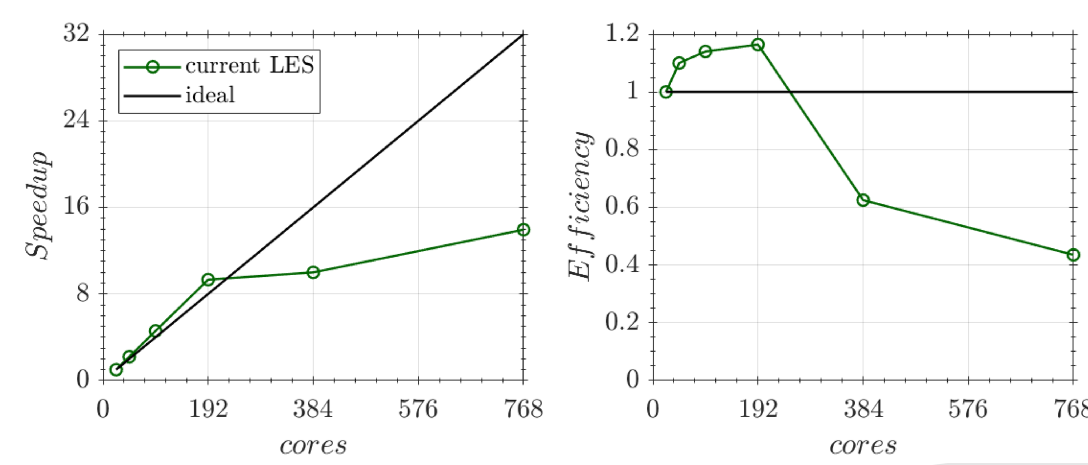


Fig. 5: Quantification of the parallel performance study

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