Visualising uncertainty in location and development of thermal stratification layers

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High-fidelity simulations of thermal hydraulic problems generate large number of flow artifacts arising from turbulence, buoyancy or complex geometry. Some of these features have engineering significance and are studied under representative operational conditions to evaluate reliability or performance of a given physical system.

In particular, the development and persistence of thermal stratification in pipeline networks exhibiting large thermal transients may severely impact the lifetime of the network. Characterising such regions and uncertainties in their location or longevity will help predict areas of high-stress, low-cycle fatigue and consequently improve risk analysis practices.

This paper presents a methodology for studying uncertainties associated with the location and temporal development of thermal stratification. The benchmark case considered here is a U-shaped pipe based on [1]. The simulation is a coupled 3D model of conjugate heat transfer between the fluid and pipe wall during a hot shock transient. Fluid turbulence is modelled with large eddy simulation and buoyancy with Boussinesq approximation. An ensemble calculation is performed by varying hot shock parameters.

To detect stratification we developed an automated procedure based on mean-shift filtering and a simple connectivity function. The regions are labeled across all time steps and test cases. We then apply contour boxplots introduced in [2] to characterise the median, the 50% envelope and outliers. The complete algorithm performs feature detection algorithm with in-built uncertainty measures.

The methodology discussed here is not limited to simulations and can be easily extended to experimental results with image or volume data or to facilitate simulation-experiment comparisons. Further development of automated post-processing and associated uncertainty measures are necessary to enable reliable digital certification procedures.

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References

[1] P. L. Viollet. "Observation and numerical modelling of density currents resulting from thermal transients in a non rectilinear pipe". In: *Journal of Hydraulic Research* 25.2 (1987), pp. 235–261.

[2] R.T. Whitaker, M. Mirzargar, and R.M. Kirby. "Contour Boxplots: A Method for Characterizing Uncertainty in Feature Sets from Simulation Ensembles". In: *Transation on visualization and compter graphics* 19.12 (2013), pp. 2713–2722.