ANSYS CFX Simulation Of T-junction Mixing Phenomena and Validation against Vattenfall Experiment Results

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Introduction

One of the important safety issues at nuclear power plants is the mixing of hot and cold water at a T-junction. The thermal fluctuations from the mixing can cause thermal fatigue at the pipe walls after the junction, and bring about its failure. Cases like this have happened in the past such as in Civaux-1 plant incident in France in 1998.

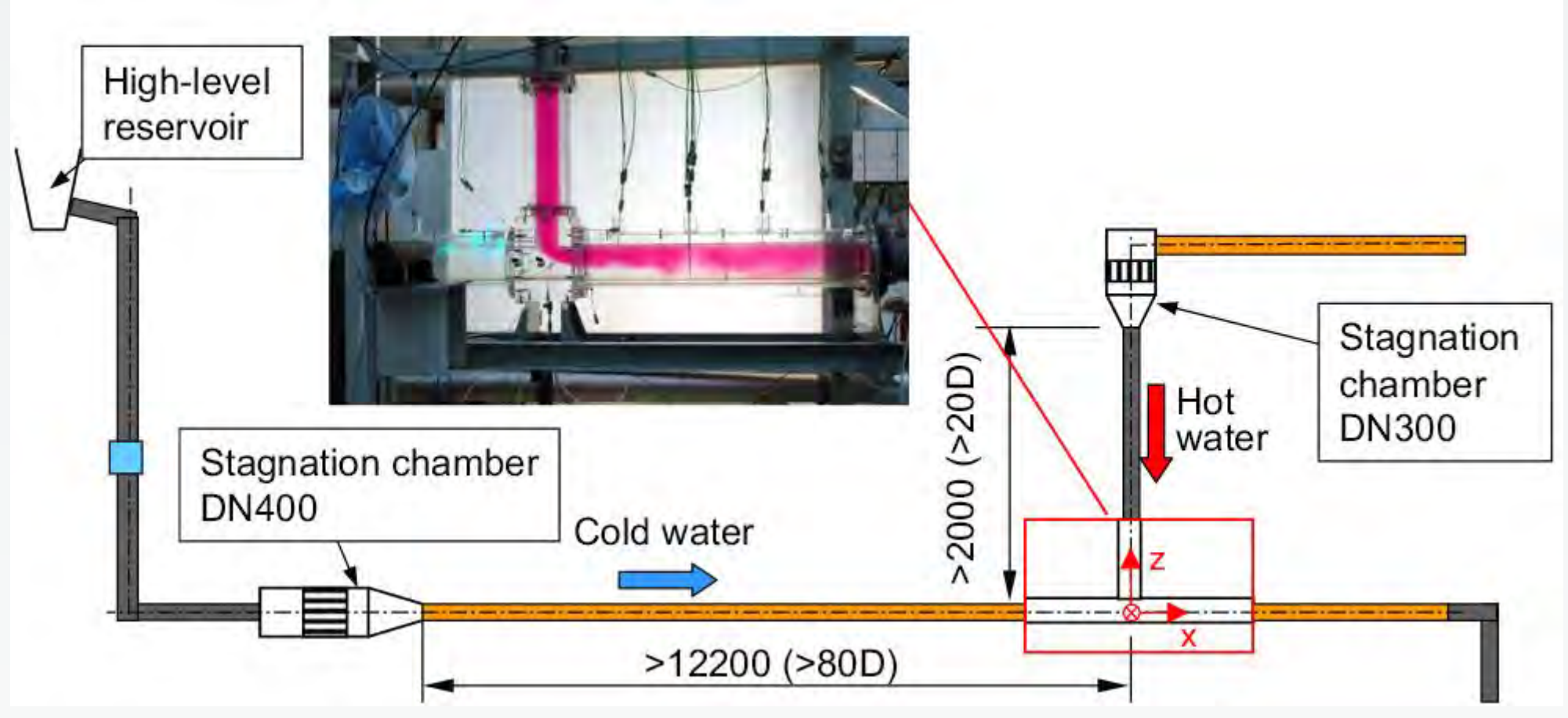
That is why computationally studying the T-junction mixing phenomena in order to determine the location of failure and frequency of mixing are important, especially against experimental data to be validated against.

Experiment

The Alvkarleby laboratory of Swedish power company Vattenfall performed a T-junction experiment as part of a blind benchmark study 2008. The experiment involved water at two different temperatures mixing at a T-junction.

Horizontal pipe of 140 mm diameter, entering at 19° C and flowing at 9 l/s.

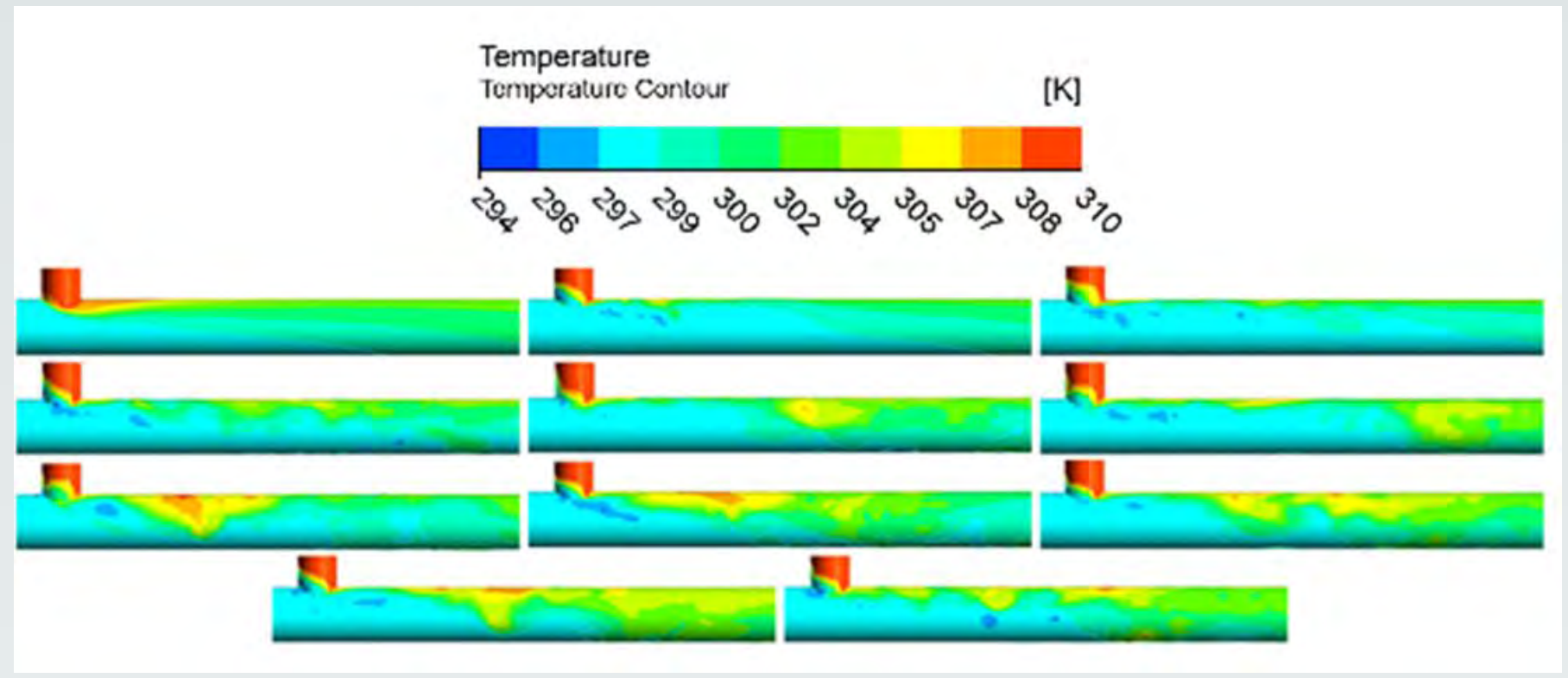
Vertical pipe of 100 mm diameter, entering at 36° C and flowing at 6 l/s.



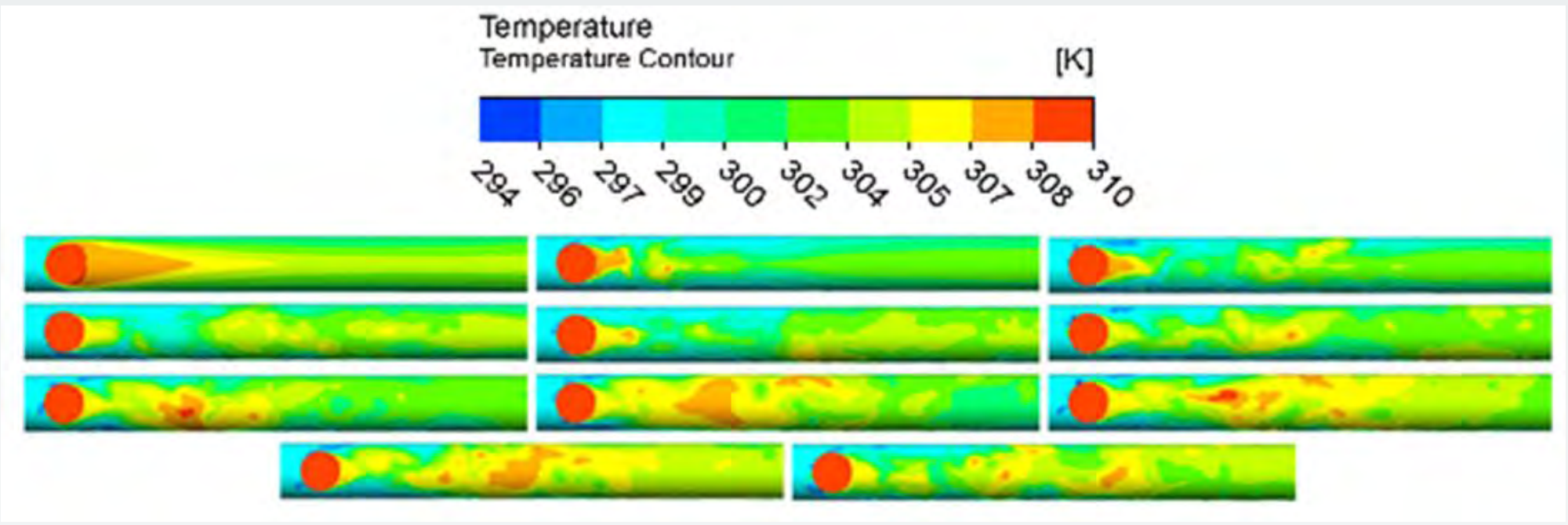
Computational setup

- The geometry was created with ANSYS DesignModeler consisting of a horizontal pipe 15.2 m in length and a vertical pipe 2.2 m in length, attaching to the horizontal one 11.2 m downstream.
- The tetrahedral mesh consisted of 773,357 nodes and 2,590,870 control volumes with a minimum orthogonal quality of 0.19.
- The steady-state results were computed using the Sheer Stress Transport (SST) model of turbulence, which converged with RMS values less than 10^{-4}.
- The steady-state results were used as initial conditions for the transient run which used the Dynamic Smagorinsky-Lily model of the Large Eddy Simulation (LES) for its turbulence modeling. The RMS residual values of the transient run stayed below 10^{-4} after less than 100 time-steps.
- The transient solution was run for 26 s total and time-steps of 0.005 s.

Results



Sideview of temperature contours of the outer surface of the water at 0.00, 0.50, 1.00, 1.50, 2.00, 2.50, 3.00, 3.50, 4.00, 4.50, and 5.00 s of the transient solution



Topview of temperature contours of the outer surface of the water at 0.00, 0.50, 1.00, 1.50, 2.00, 2.50, 3.00, 3.50, 4.00, 4.50, and 5.00 s of the transient solution

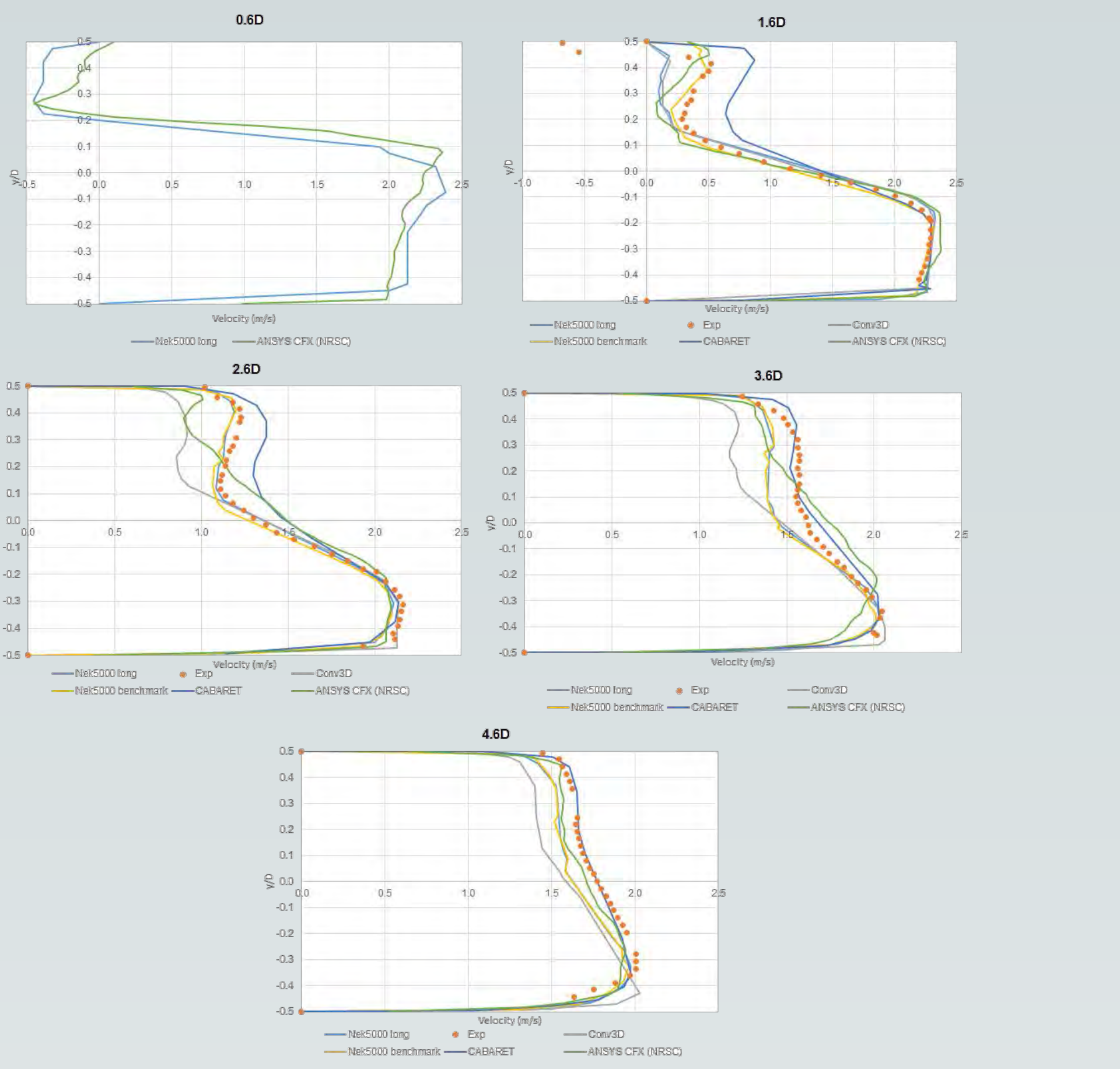
The next figures compare the results of the current analysis experimental data and computational results obtained with Nek5000, CABARET, and Conv3D as described in Obabko et al. (2011).

Average velocities: $u = \frac{1}{M}\sum_{n=1}^{M} u_n$

RMS velocities: $u' = \sqrt{\frac{1}{M}\sum_{n=1}^{M}(u_n - u)^2}$

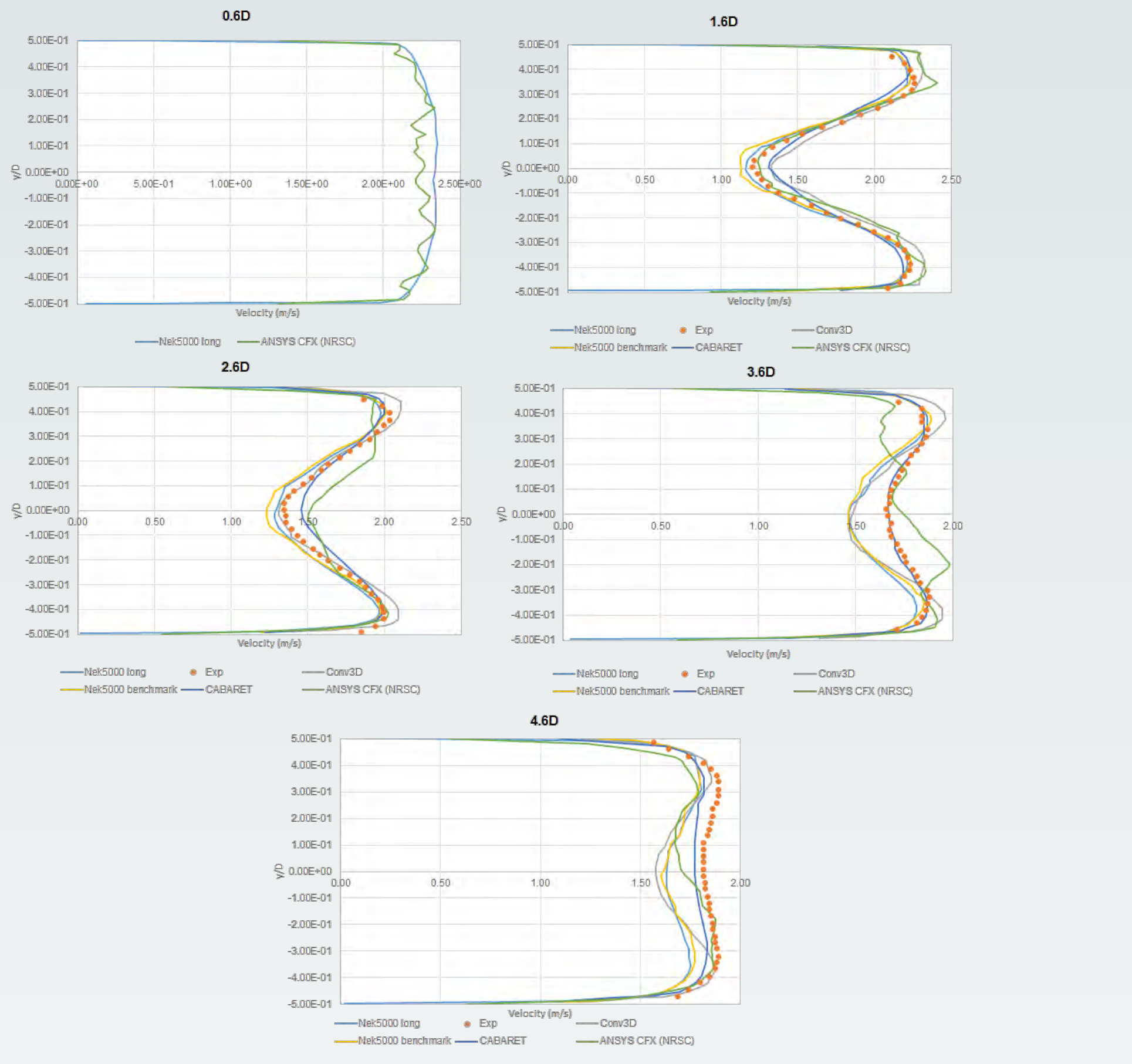
These results were compared 0.6 (where there were no experimental results available), 1.6, 2.6, 3.6, and 4.6 times the diameter of the main pipe downstream from the junction.

These figures were calculated between 6-26 s after the initiation of the transient solution, with discrete velocity data taken every second

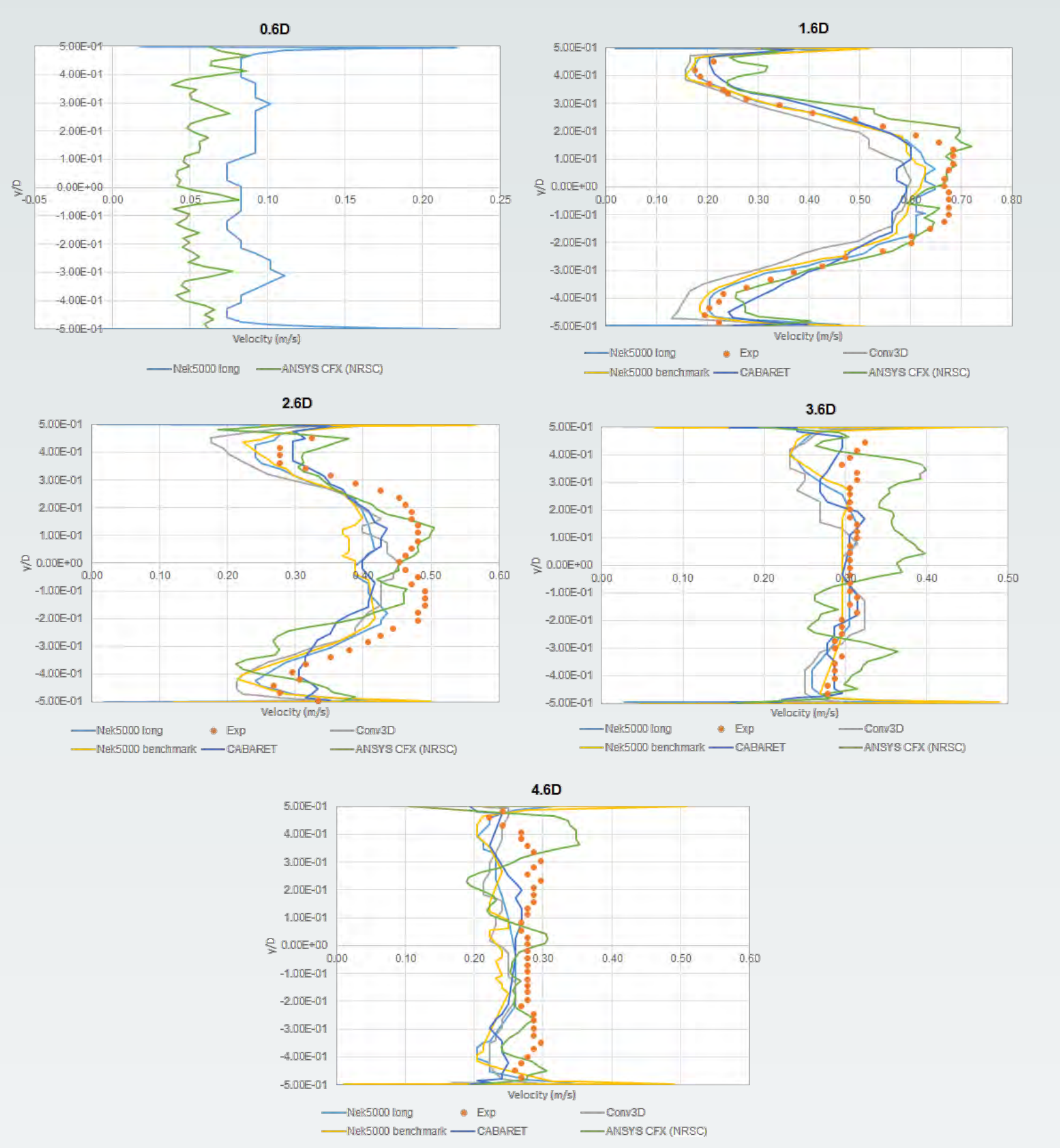


Sideview average velocities after the T-junction

Sideview RMS velocities after the T-junction



Topview average velocities after the T-junction



Topview RMS velocities after the T-junction

Summary

Results showed consistency with benchmark and experimental results, showing that the LES dynamic model of ANSYS CFX could successfully be employed to simulate a transient solution of the T-junction mixing and to predict the location of thermal fatigue from temperature differences

The time-steps used were 0.005 s, which were larger than those used in other CFX studies among the blind simulations.

A future mesh sensitivity study with spatial and time refinements as well as a different type of mesh can demonstrate whether they cause any significant deviation from the current results or further accuracy compared to the experimental results.

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Acknowledgments

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