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Investigation of the Thermal Mixing in a T-Junction Flow With Different SRS Approaches

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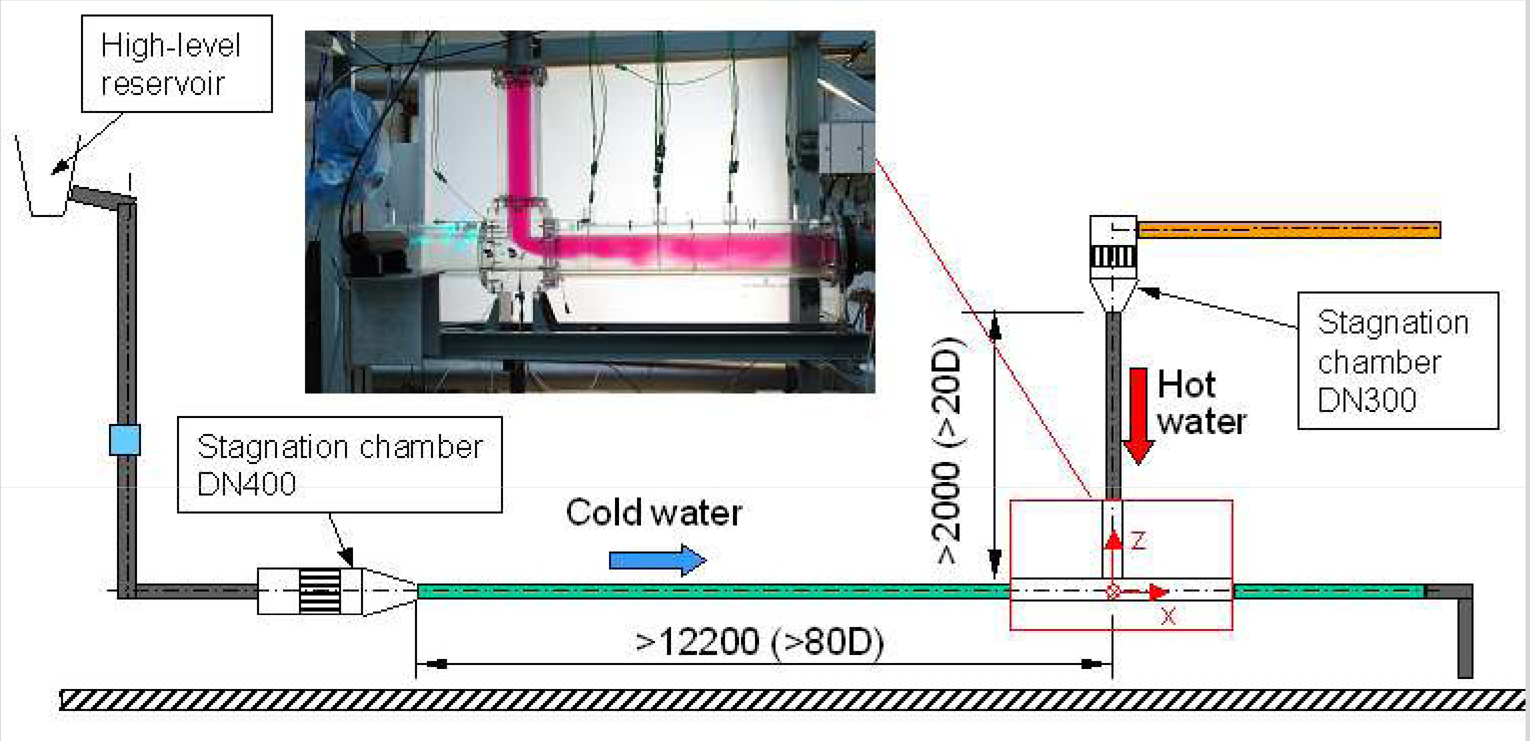
Outline

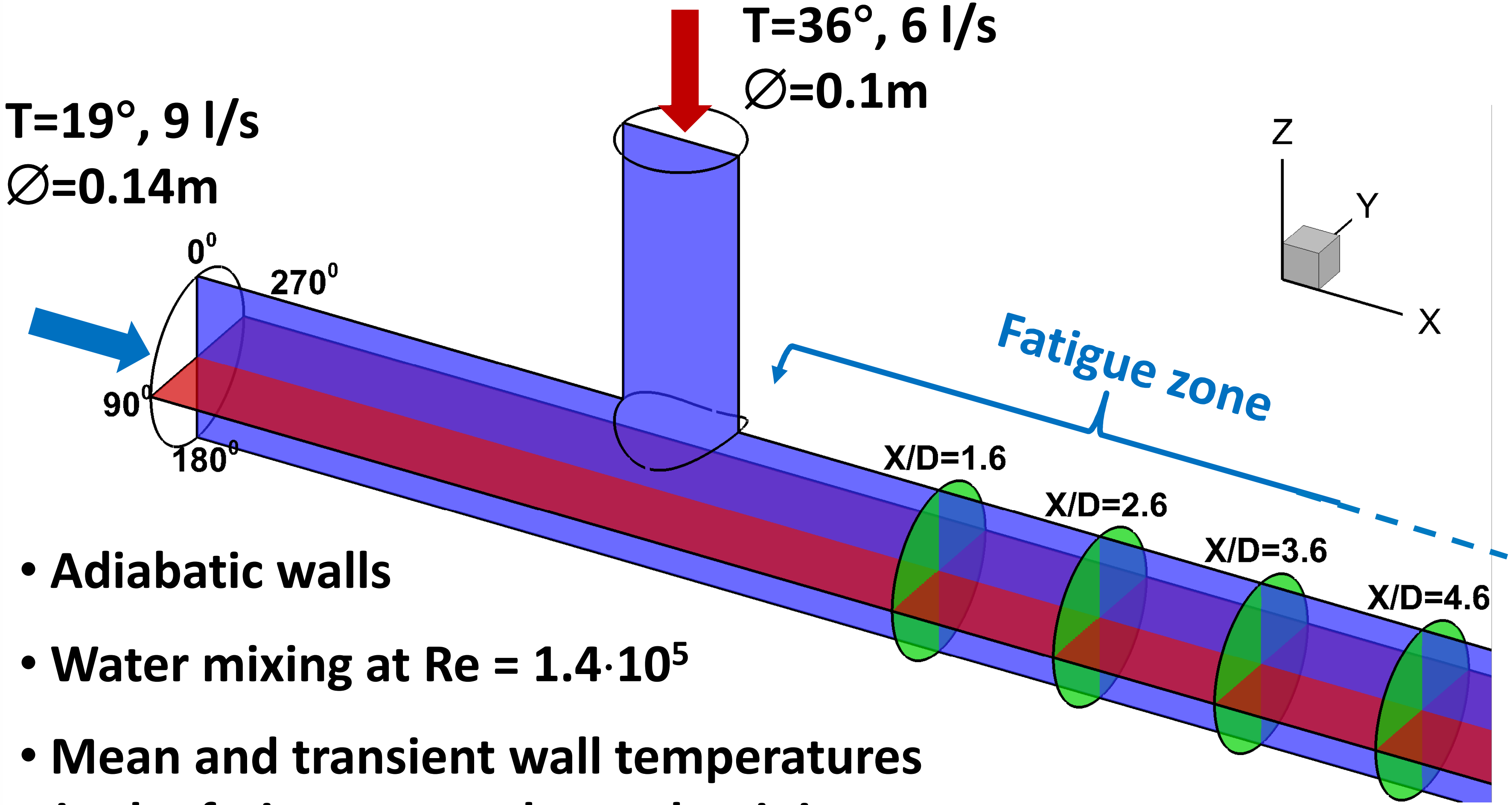
- The OECD/NEA Benchmark on thermal mixing in T-junctions
- The Vattenfall T-junction experiment
- CFD test case description
- Results
- Summary

OECD/NEA Benchmark on Thermal Mixing in T-junctions



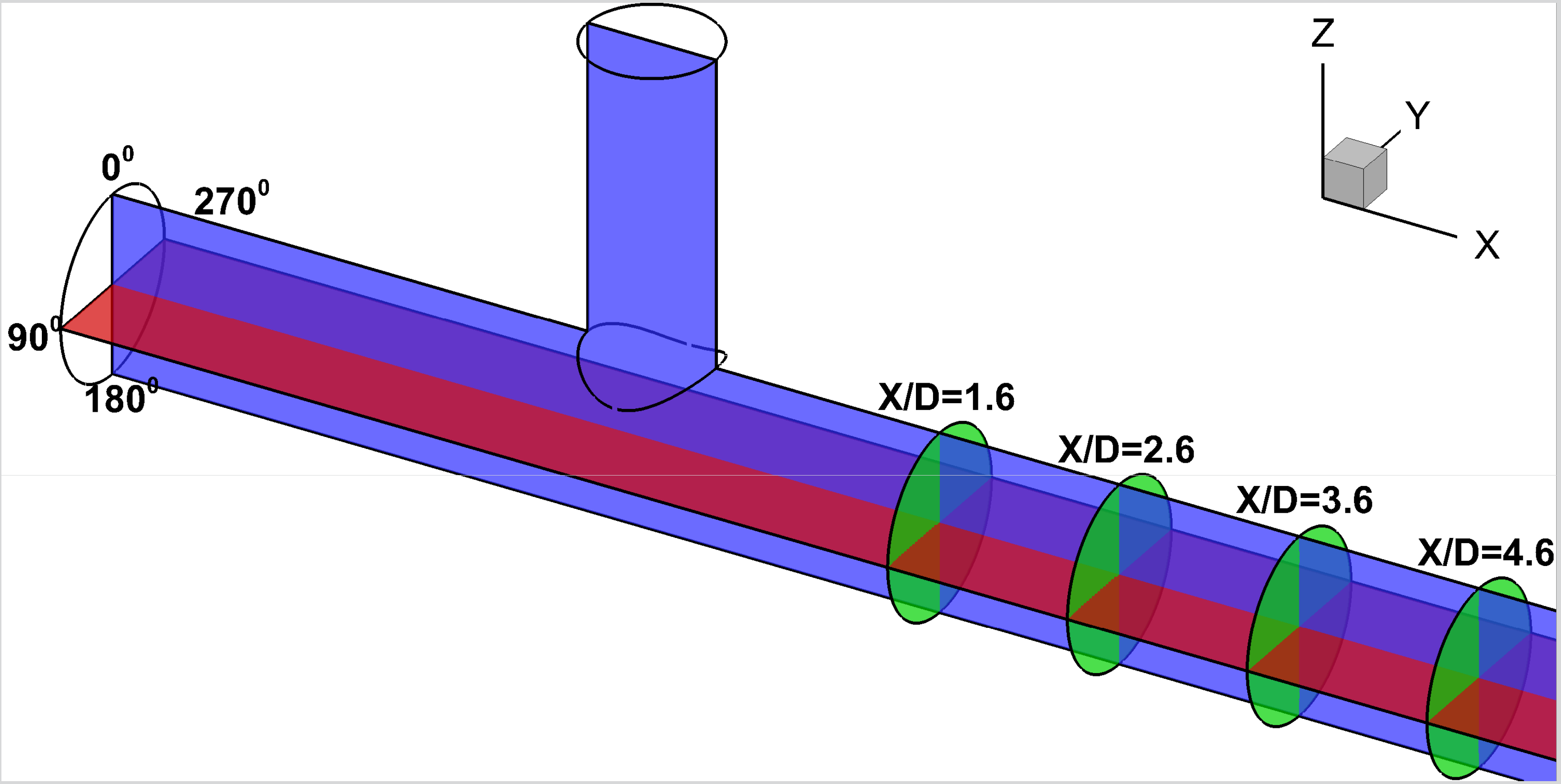
- OECD/NEA Benchmark, 2009-2010; CSNI Report in 2011
- Odemark, Y. et al., 2009. High-Cycle Thermal Fatigue in Mixing Tees: New Large-Eddy Simulations Validated Against New Data Obtained by PIV in the Vattenfall Experiment. In *Proceedings of the 17th International Conference on Nuclear Engineering*.
- Mahaffy, J., 2010. Synthesis of Results for the T-Junction Benchmark. In *CFD4NRS-3 Conference on Experimental Validation of CFD and CMFD Codes to Nuclear Reactor Safety Issues*. Washington, DC, USA, p. 3.

Flow Schematic



- Adiabatic walls
- Water mixing at Re = $1.4 \cdot 10^5$
- Mean and transient wall temperatures in the fatigue zone: thermal striping

Available experimental data

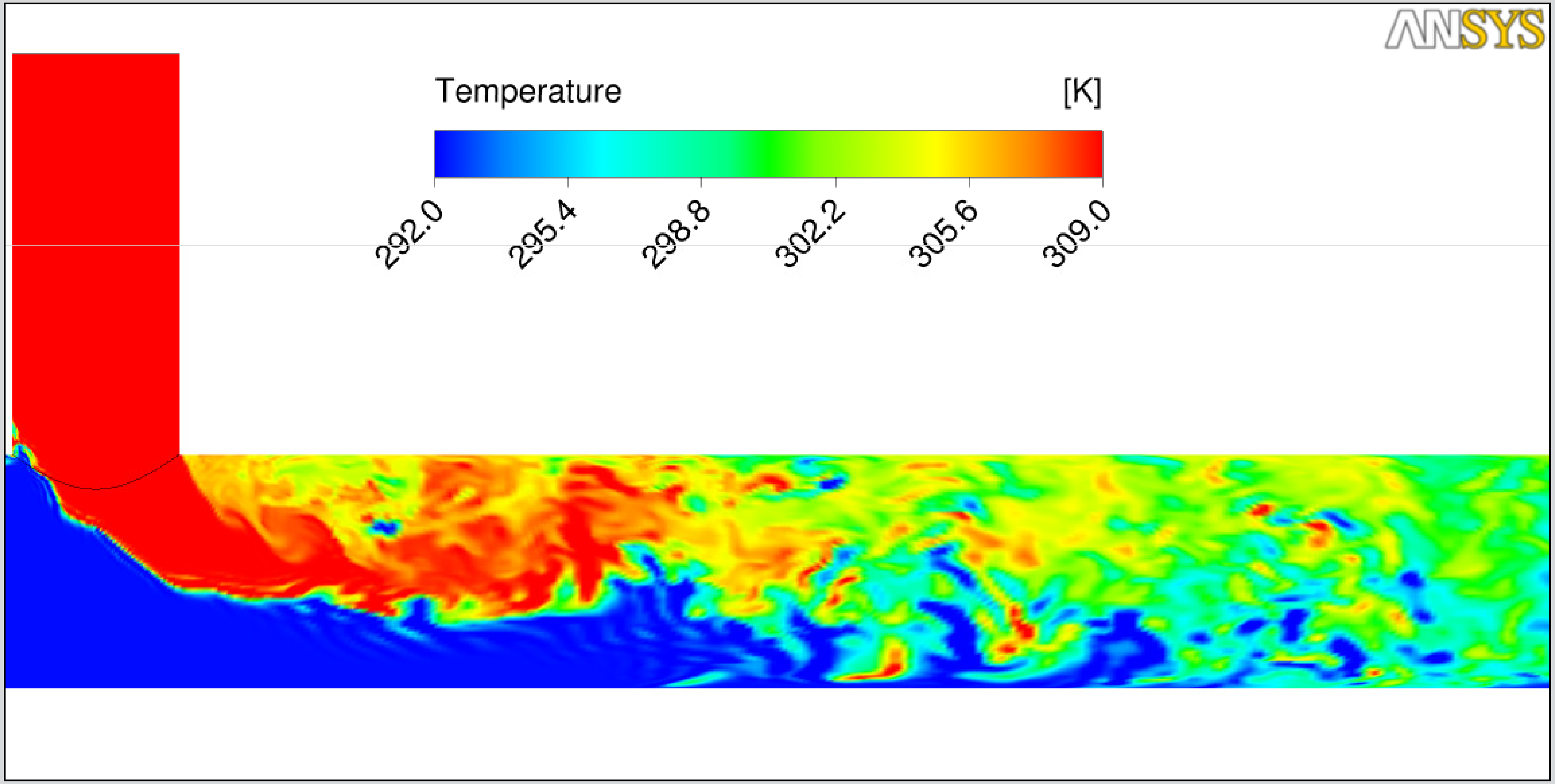


mean U,V,W & RMS: vertical & horizontal central lines at shown cross-sections

T_{mean} & RMS: x-lines at walls at 0°, 90°, 180°, 270°

Thermal Striping Phenomenon

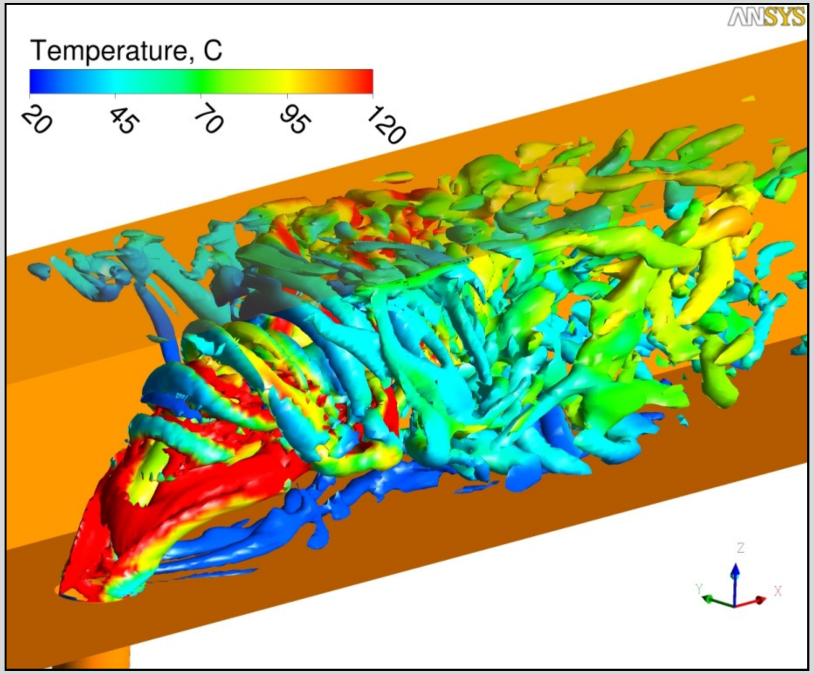
- Intensive turbulent mixing downstream the T-junction
- Strong temperature fluctuations near the wall, top & side walls in particular



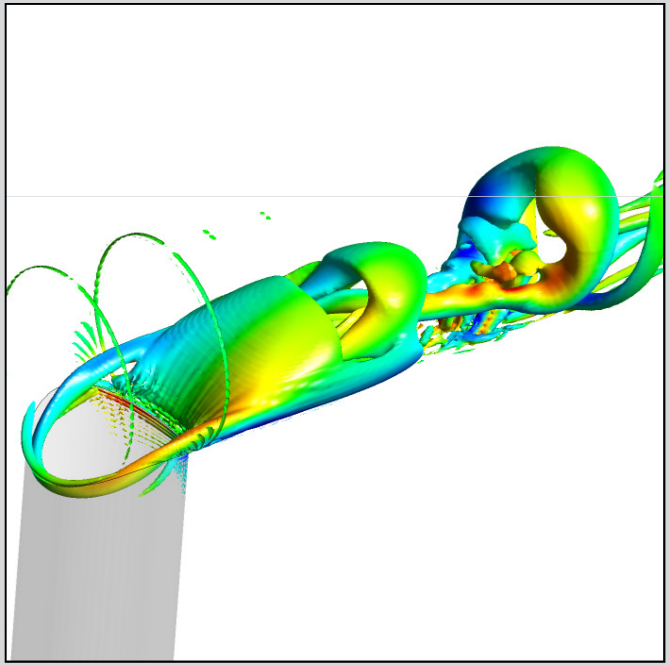
Expected SRS Model Behavior?

Globally or locally unstable, or even stable?

Jet in cross-flow, SAS



T-junction, SAS, bounded CD

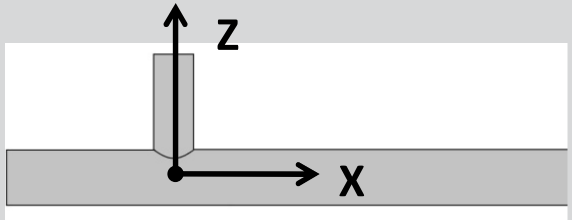


Experiment: very fast mixing, no large stable vortices

Domain and Grid

Main pipe: $-3 \leq x/D \leq 20$, $D=0.14m$

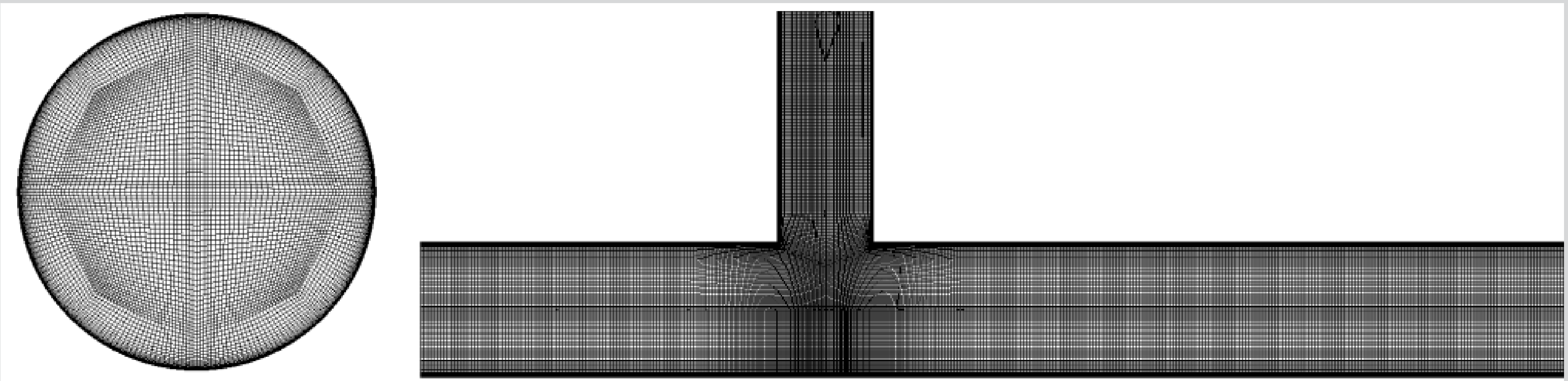
Branch pipe: $z/d \leq 3.1$, $d=0.10m$



Grid: 4.9M elements, hexahedral

Wall y^+: ~4÷6, locally up to 12 in the mixing zone

Timestep: 1 ms ➔ CFL: bulk ~0.5, mixing zone ~1 ÷ 1.5



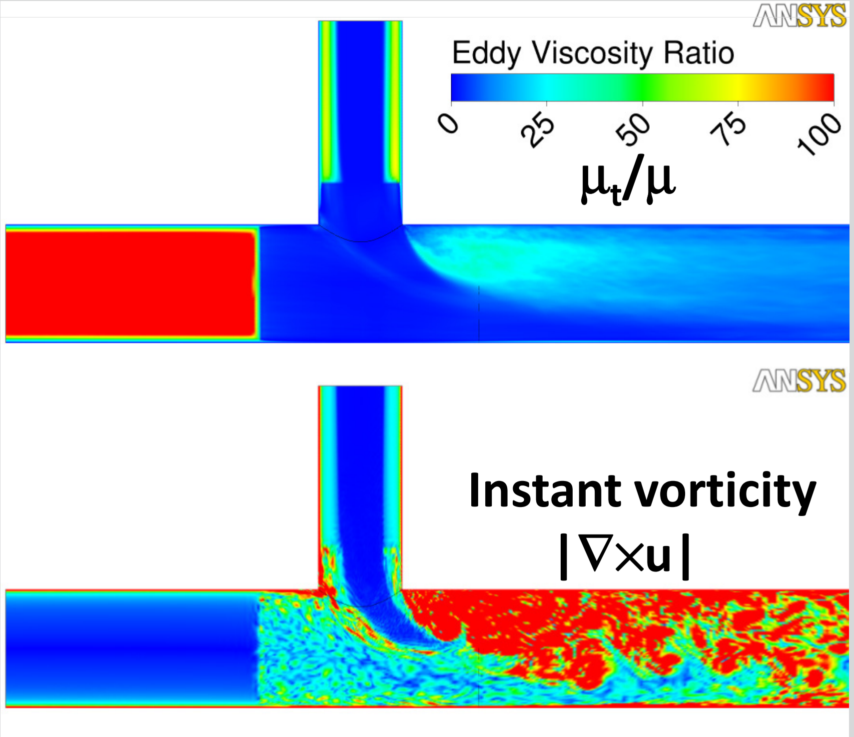
Turbulence Models: CFX

SST-SAS without Zonal LES

- Central differences (CD)
- Standard bounded CD (BCD)
- Weakly bounded CD (WBCD)

SST-SAS with Zonal LES

- Forcing planes ½∅ upstream the junction
- WBCD



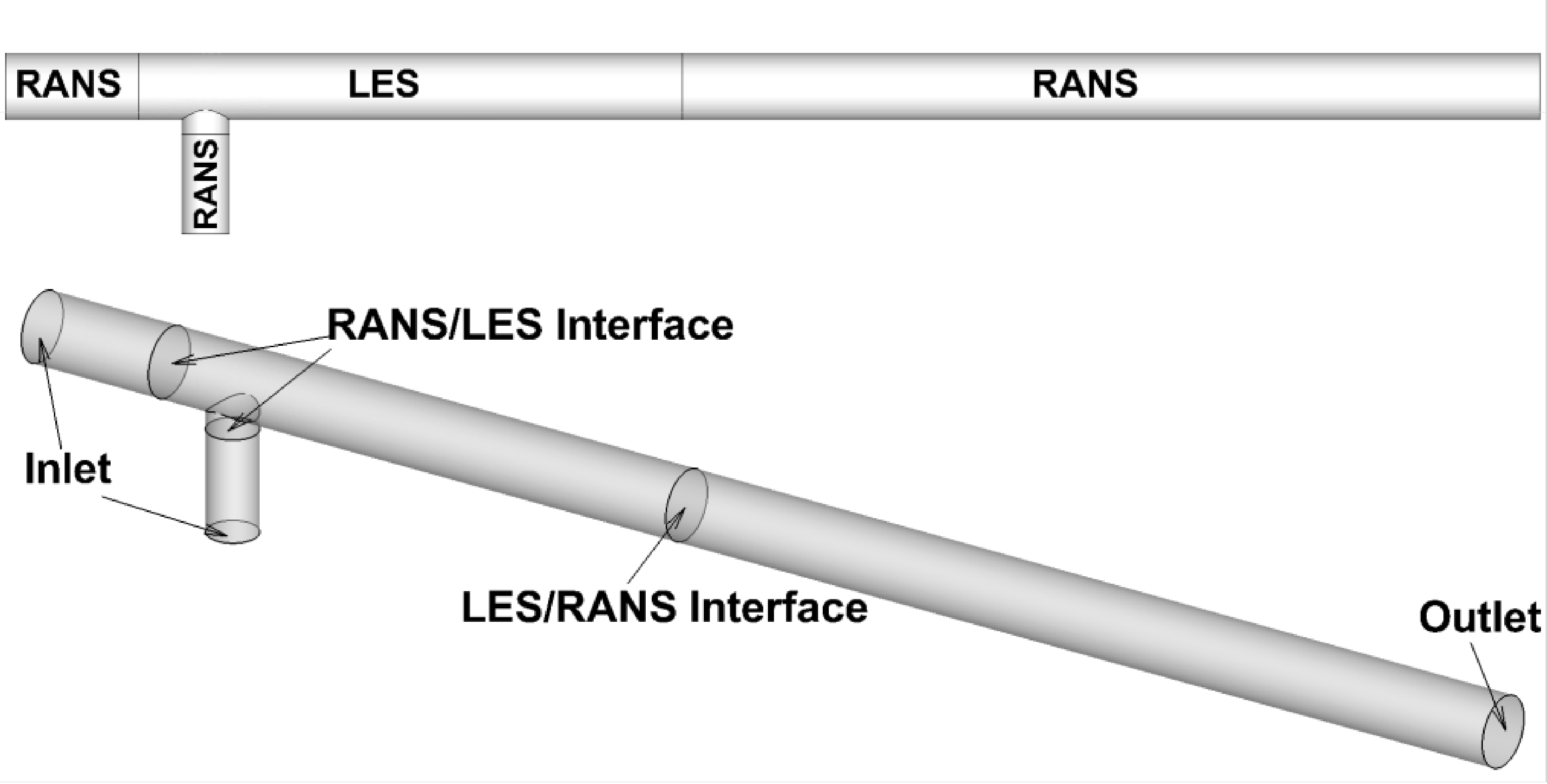
Turbulence Models: FLUENT

FLUENT: SAS, DDES and Embedded LES

ELES Setup:

- RANS/LES interface: Vortex method, 1000 vortices
- LES zone: Wall-Modeling LES (WMLES)

Advection schemes: CD & BCD



CFD Model Setup

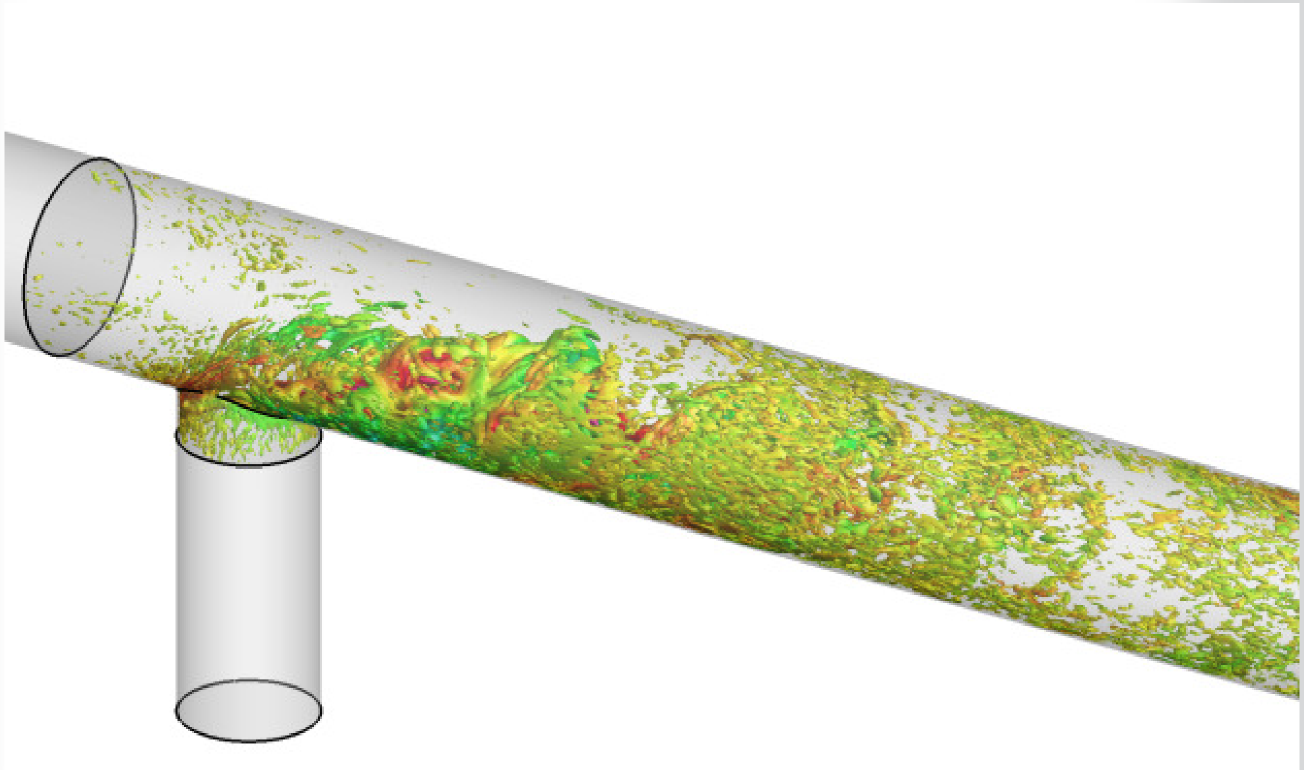
Inlet profiles

- **Main pipe (T=19°C, U_{bulk}=0.58 m/s)**
  - **Velocity and turbulence profiles from calculation in periodic pipe**
- **Branch pipe (T=36°C, U_{bulk}=0.76 m/s)**
  - **Velocity and turbulence profiles obtained from calculation in pipe flow to match the measured boundary layer thickness (δ~1cm)**

Solver setup

- **CD - Central difference or**
  BCD - bounded central difference scheme for advection terms
- **Standard scheme for pressure interpolation**
- **Green-Gauss cell based (GGCB) scheme for gradients**
- **SIMPLEC with 10 iter. per time step for pressure-velocity coupling**
- **2nd order Euler scheme for time discretization**

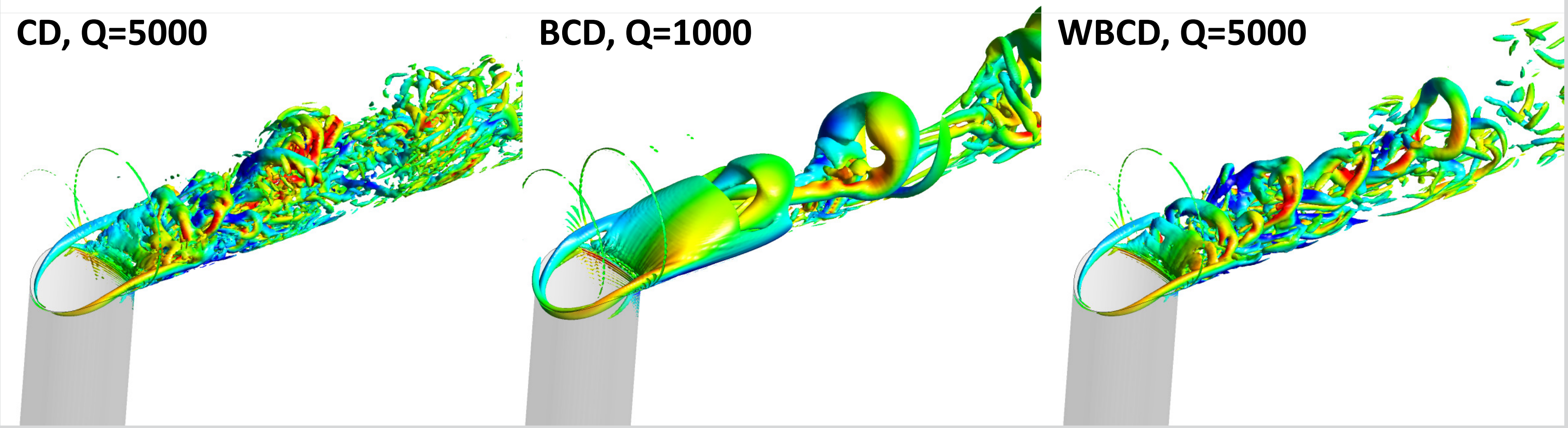
ANSYS CFX Results



Calculation of T-Junction in CFX
- Influence of Advection Scheme -

The flow was calculated in ANSYS CFX with SAS and different advection schemes available in the code:

- **Central differences (CD)**
- **Standard bounded CD (BCD)**
- **Weakly bounded CD (WBCD)**

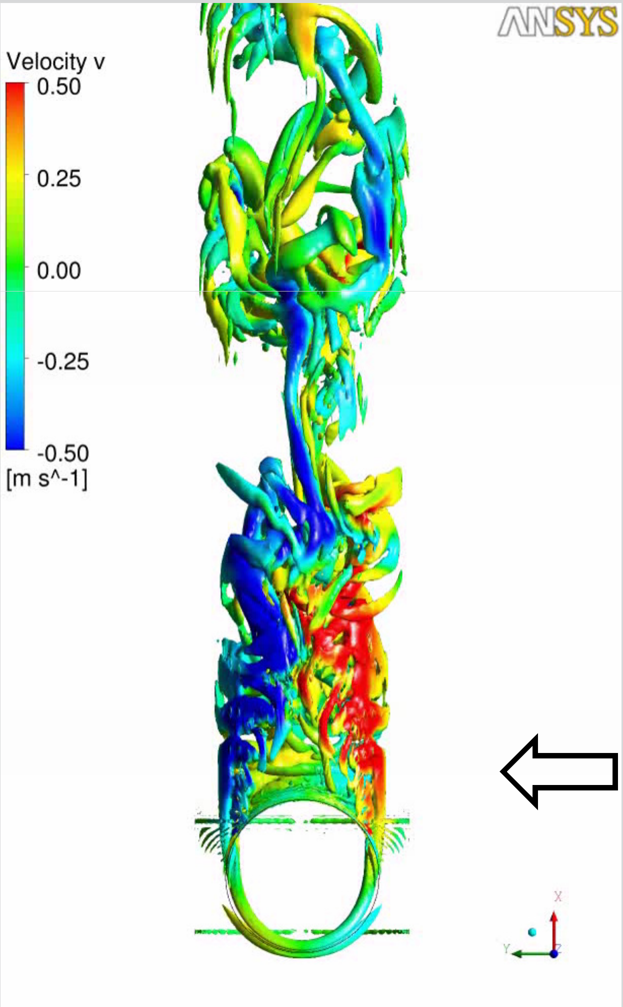


Results are strongly affected by the advection scheme.

Calculation of T-Junction in CFX
- Influence of Zonal LES, weak BCD -

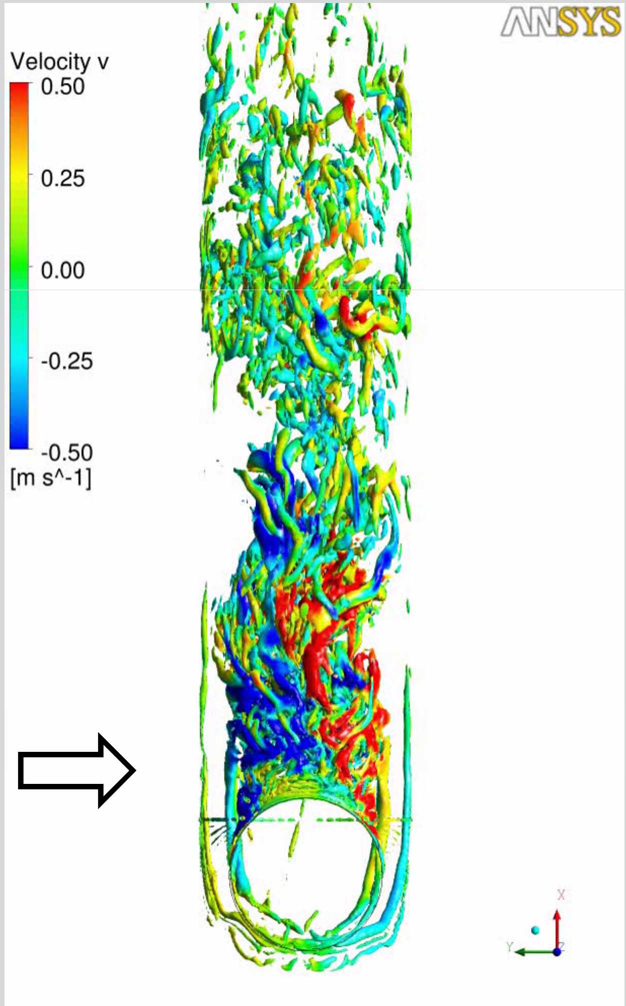
Without zonal LES, Q=1000

With zonal LES, Q=8000



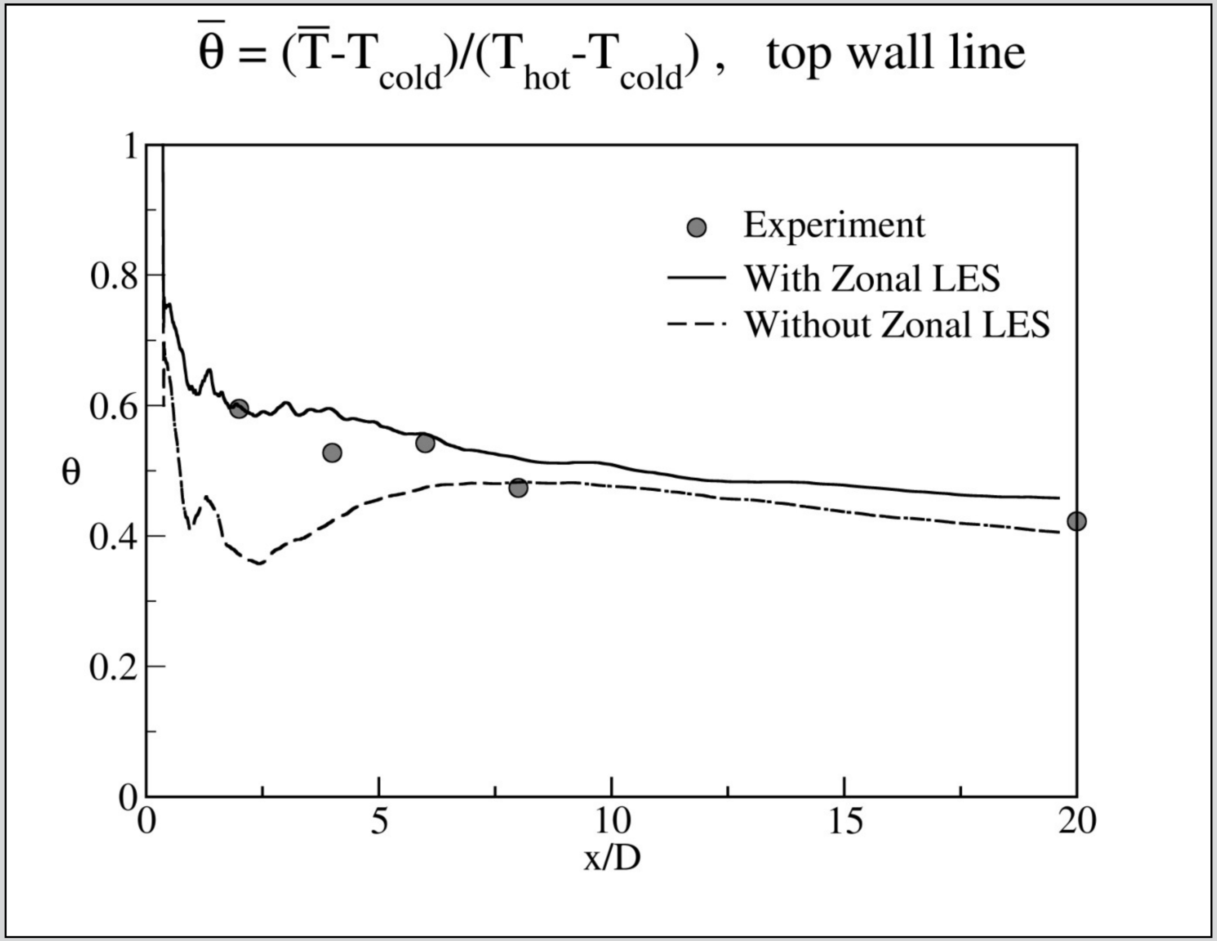
View from the top

Different mixing pattern

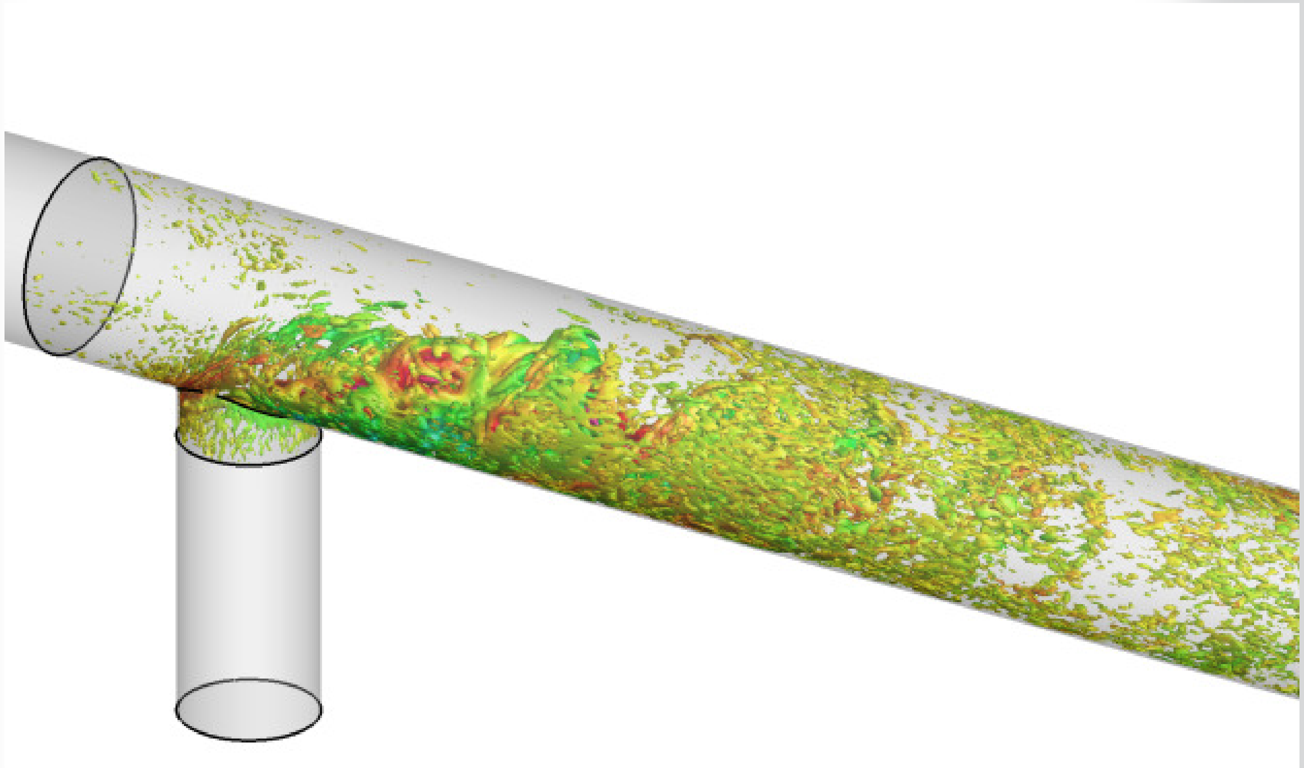


Calculation of T-Junction in CFX
- Influence of Zonal LES, weak BCD -

Wall temperature in the fatigue zone



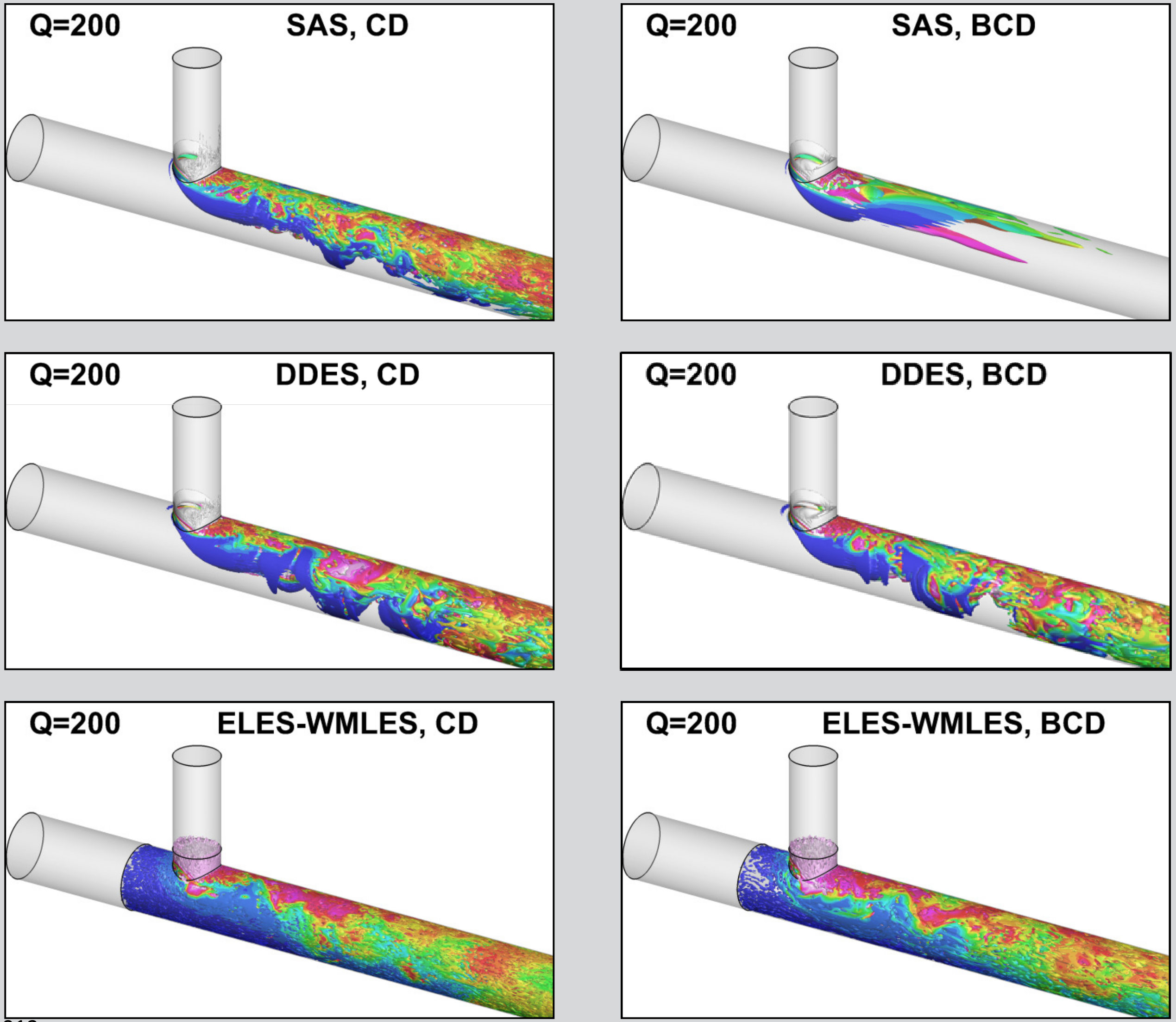
ANSYS Fluent Results



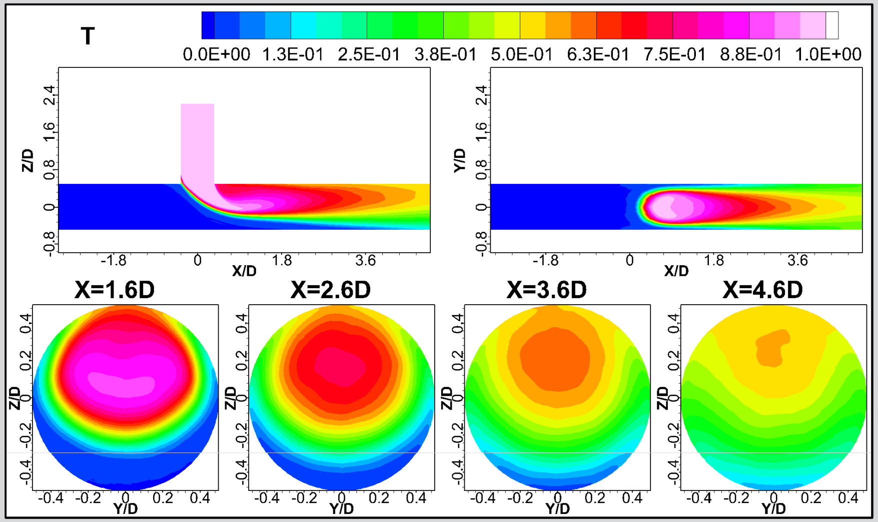
Isosurfaces of Q-criterion Colored with Temperature by Different SRS Models

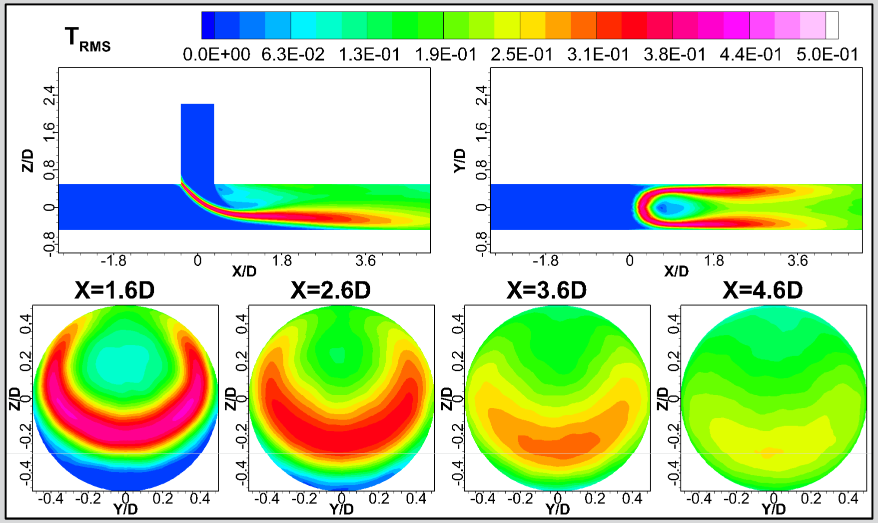
Flow results are very sensitive to numerics

- SAS & BCD scheme
  → URANS solution is obtained
  SAS & CD → LES
- For DDES the effect of numerics is smaller than for SAS but still visible on Q-criterion isosurfaces
- For ELES-WMLES there is virtually no effect of the advection scheme on the solution



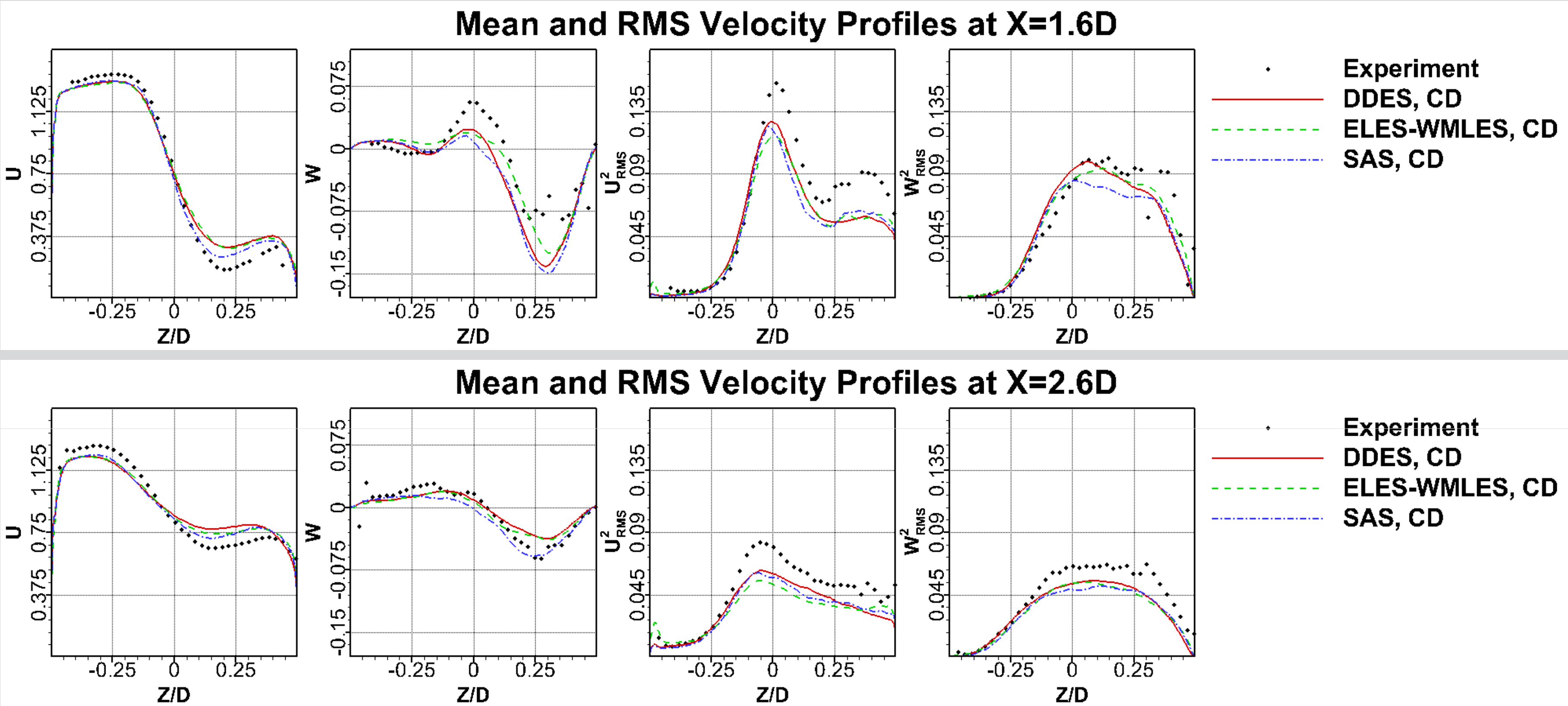
Thermal Stripping and Thermal Mixing: Mean and RMS Temperature Contours





- The hot water is strongly cooled downstream of the junction and at X/D=4.6 the flow in the pipe has nearly constant temperature
- The thermal striping phenomenon takes place mostly in the upper part of the mixing layer, where high values of temperature fluctuations (about 0.3·ΔT) are observed
- Further downstream, the magnitude of these fluctuations decreases and at X/D=4.6 it is as low as 0.1·ΔT with a nearly constant distribution across the section

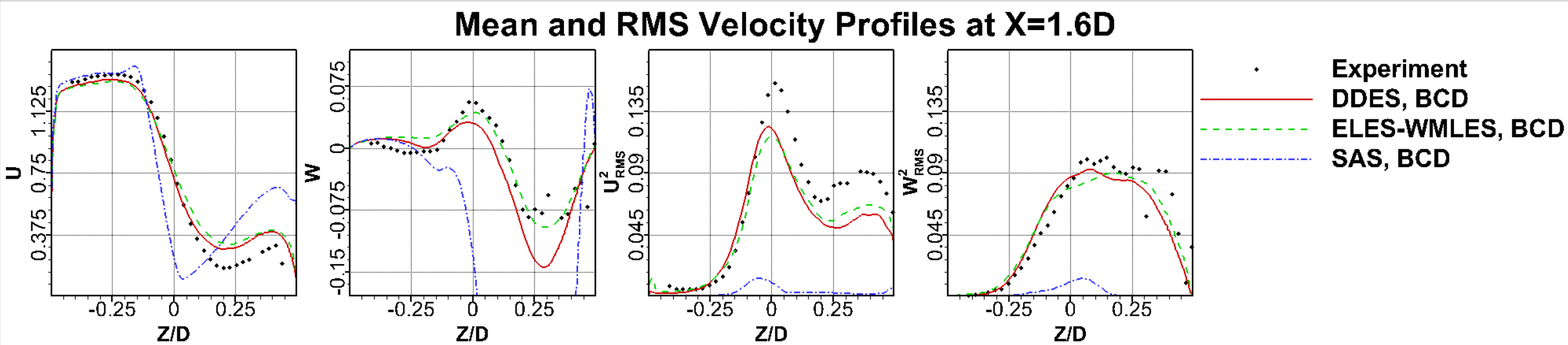
Mean and RMS Velocity Profiles for Different Models with CD Scheme

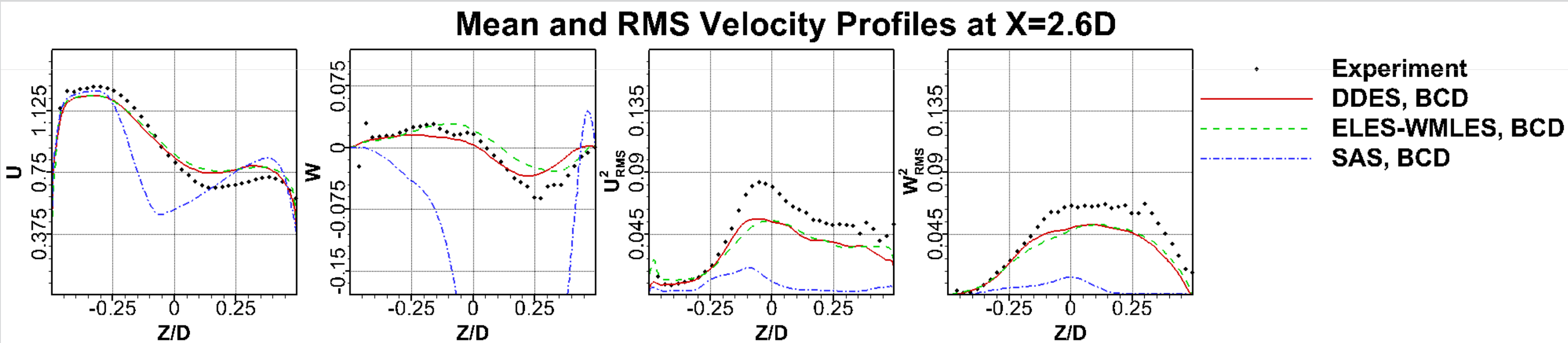


All models are able to predict the time averaged mean and RMS velocity profiles with good accuracy, when combined with the CD scheme for advection

- **Very good agreement between the results and the experimental data**

Mean and RMS Velocity Profiles for Different Models with BCD Scheme



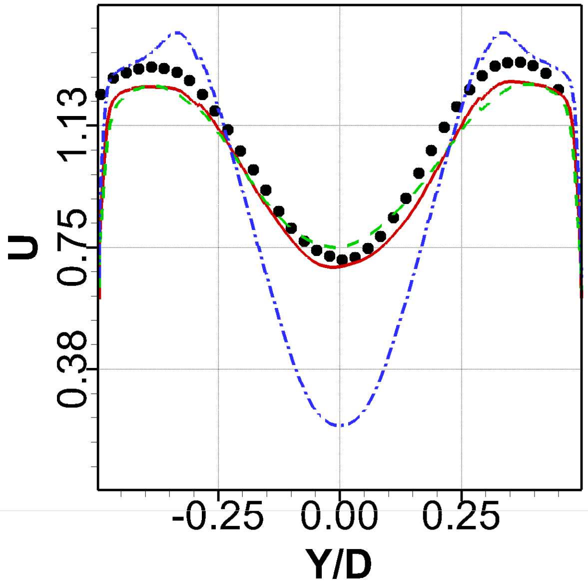


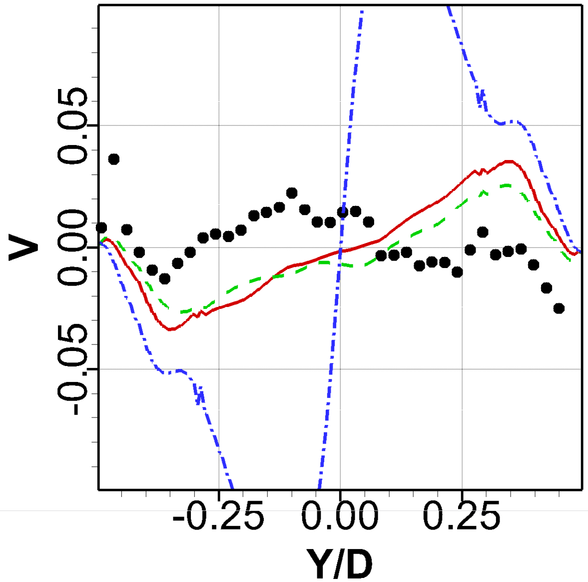
The change of the scheme from CD to BCD does not impair the solution for the DDES and ELES-WMLES approaches

SAS model reverts back to URANS mode when used with the BCD scheme

- **The lack of the resolved coherent turbulent structures downstream of the junction results in a significant underestimation of resolved RMS velocities**

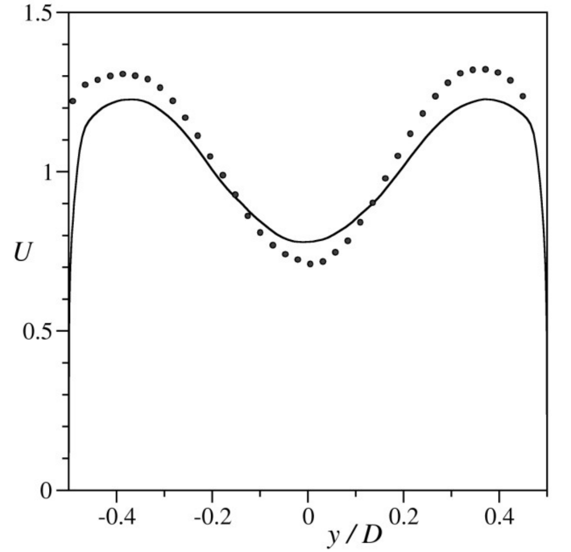
Mean velocity, horiz. line at x/D=1.6

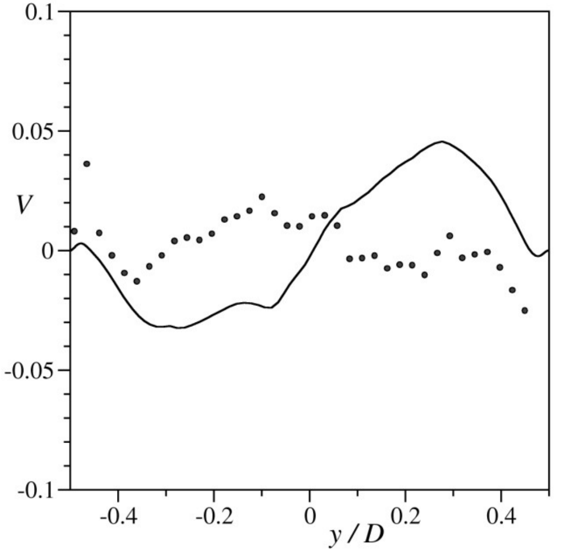




• Experiment
DDES, BCD
ELES-WMLES, BCD
SAS, BCD

Fluent





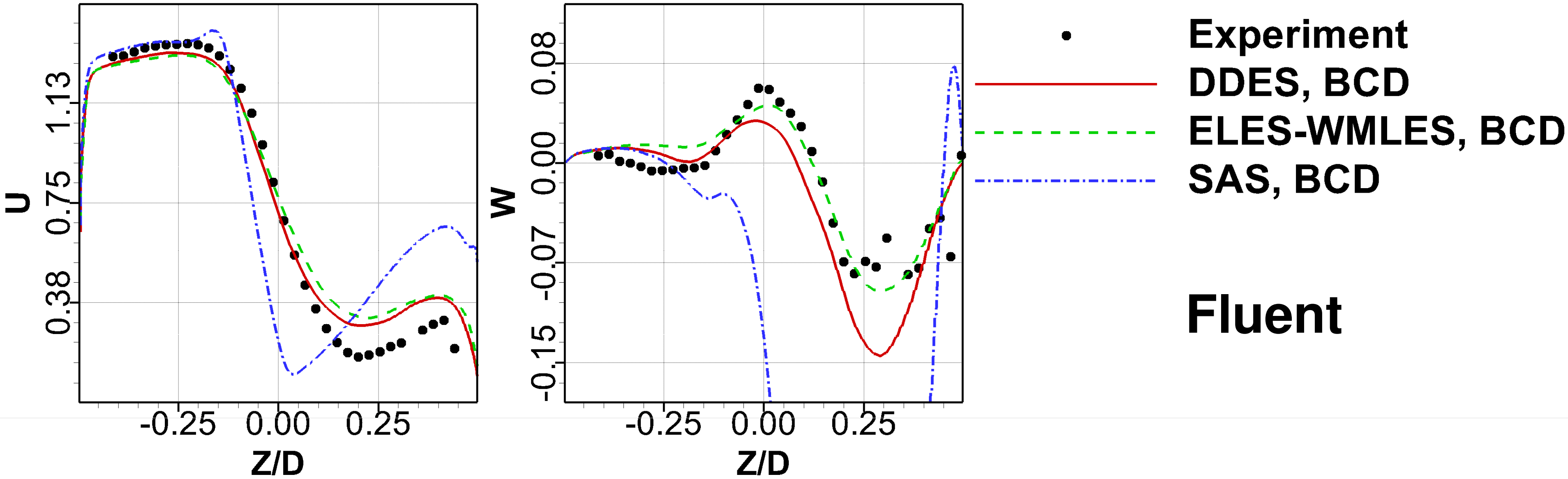
CFX

••• Experiment

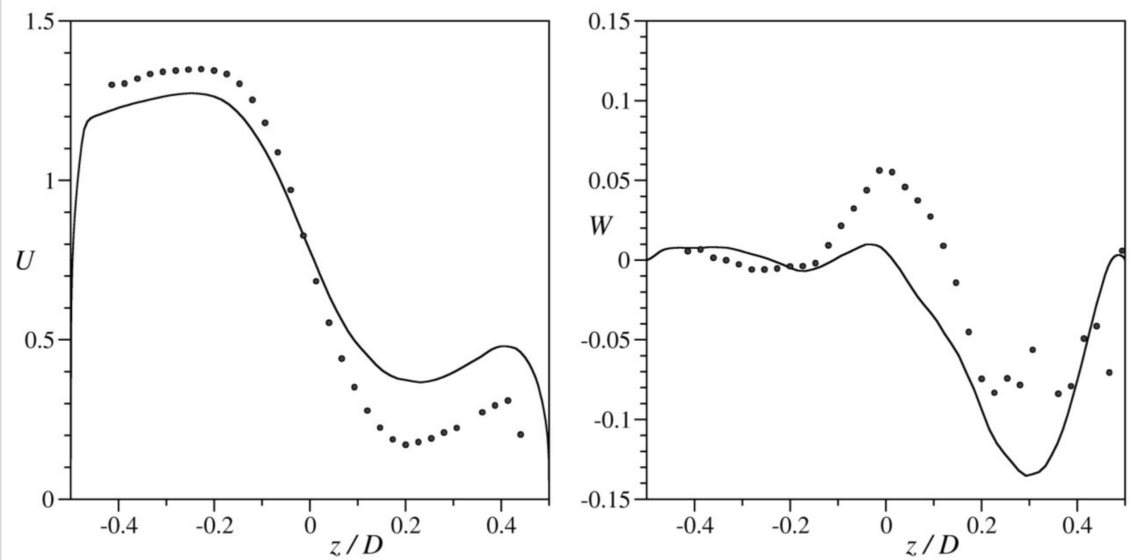
Zonal LES, weak BCD

  August 9, 2013

Mean velocity, vertic. line at x/D=1.6



Fluent

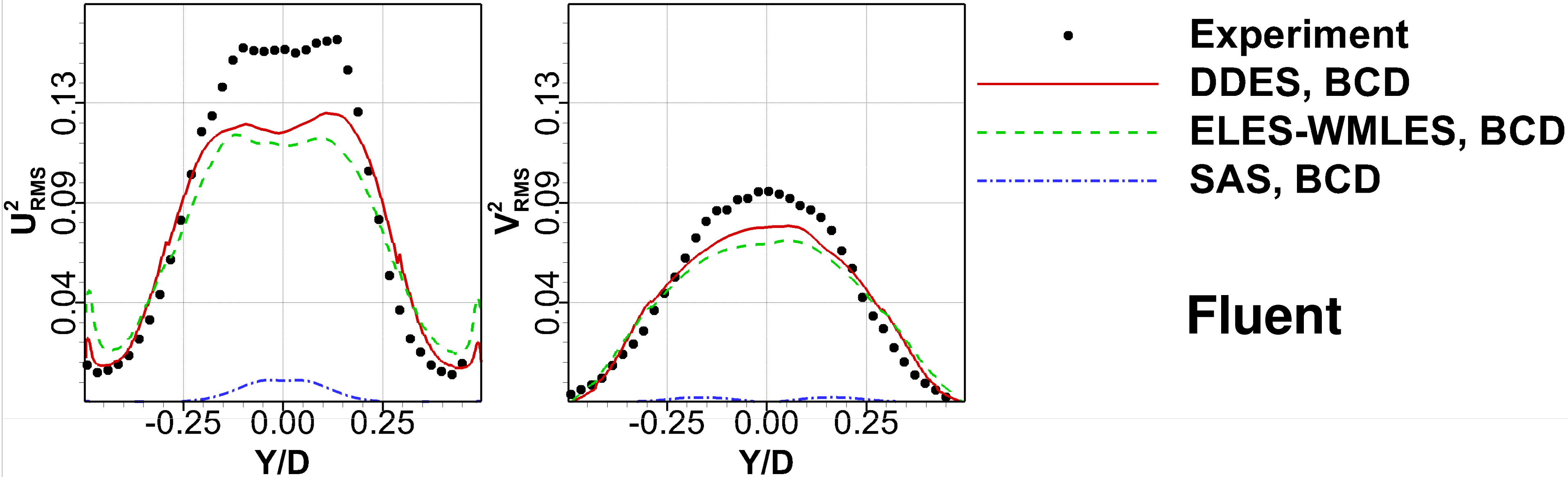


CFX

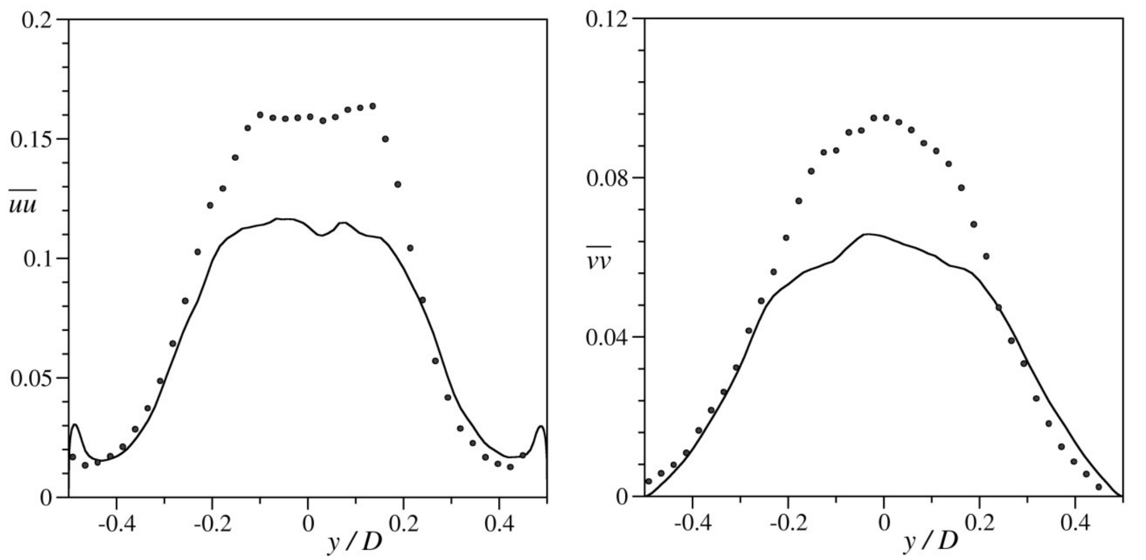
Experiment

Zonal LES, weak BCD

RMS velocity, horiz. line at x/D=1.6



Fluent



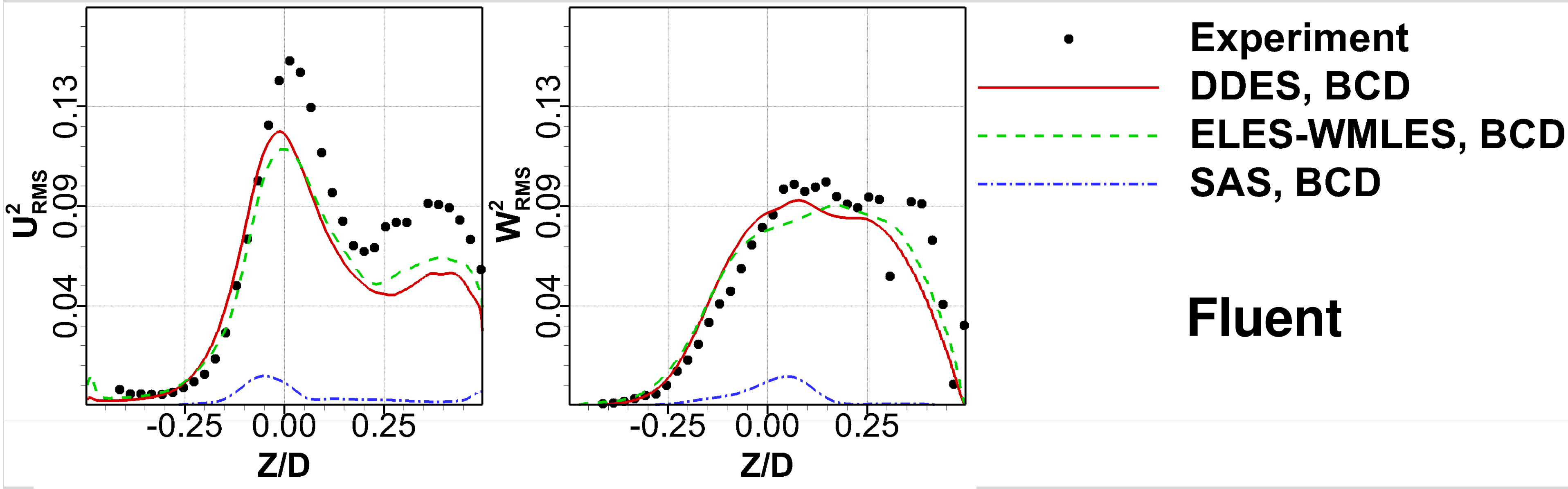
CFX

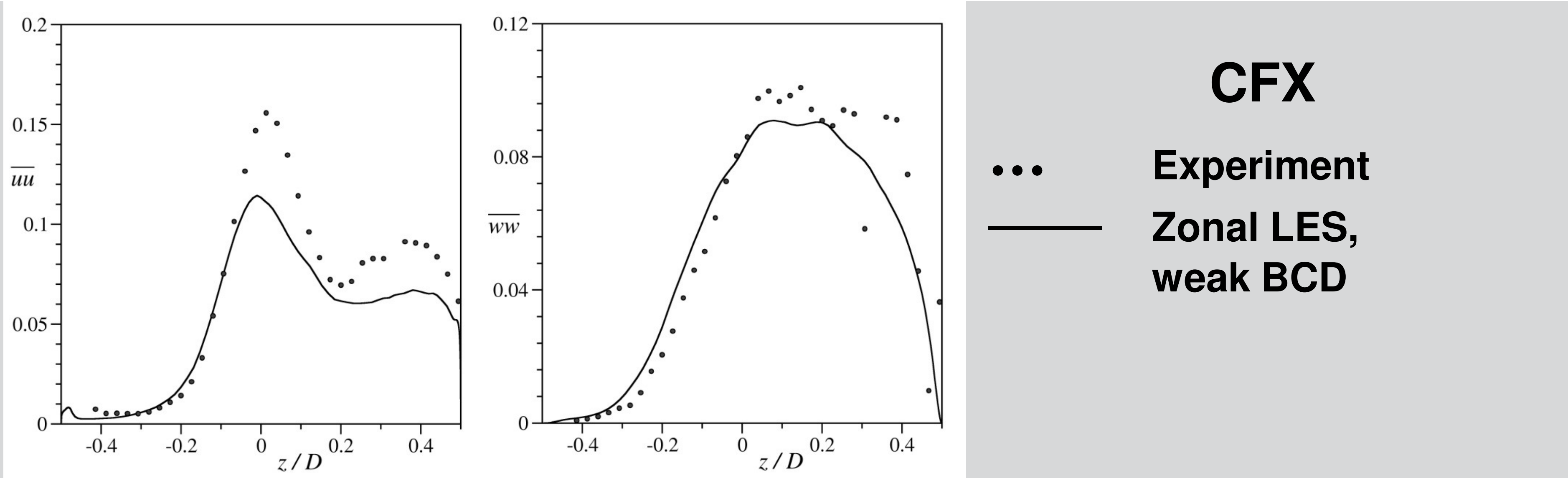
Experiment

Zonal LES, weak BCD

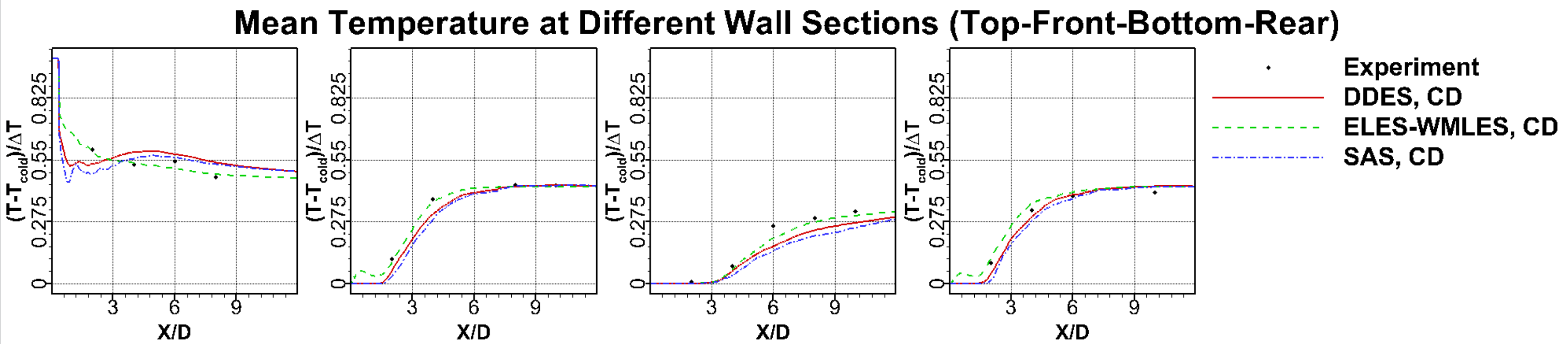
  August 9, 2013

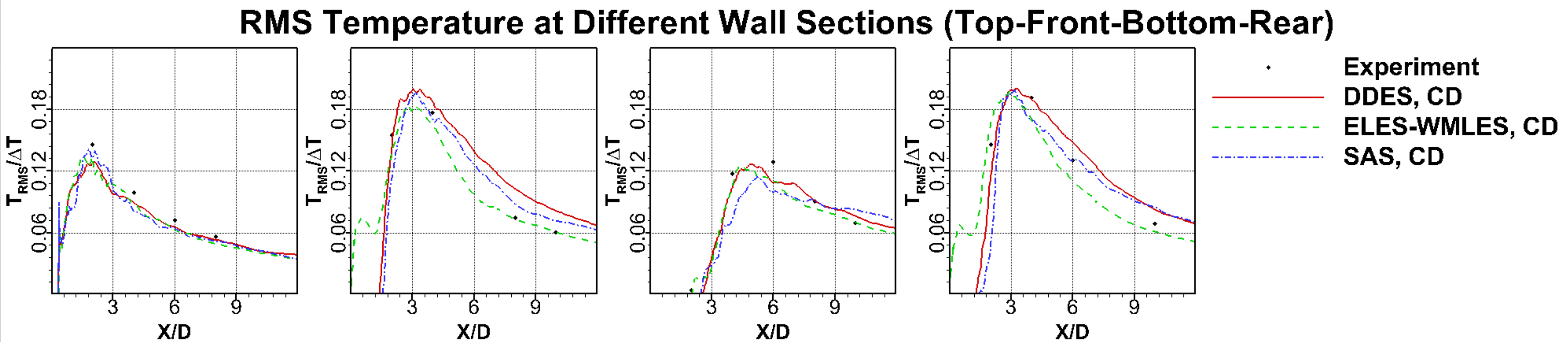
RMS velocity, vertic. line at x/D=1.6





Mean and RMS Temperature Profiles for Different Models with CD Scheme



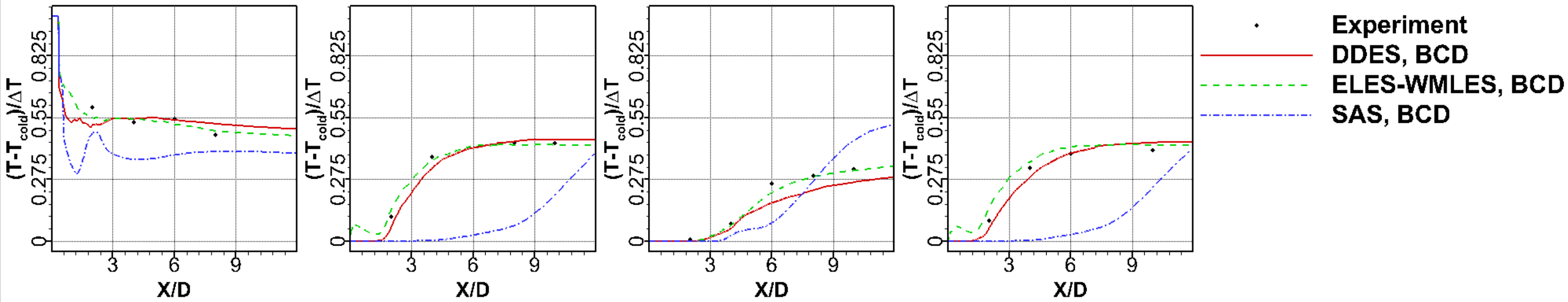


Best results are obtained with the use of ELES-WMLES approach, for which almost perfect distributions of the wall temperatures & T_{RMS} are obtained

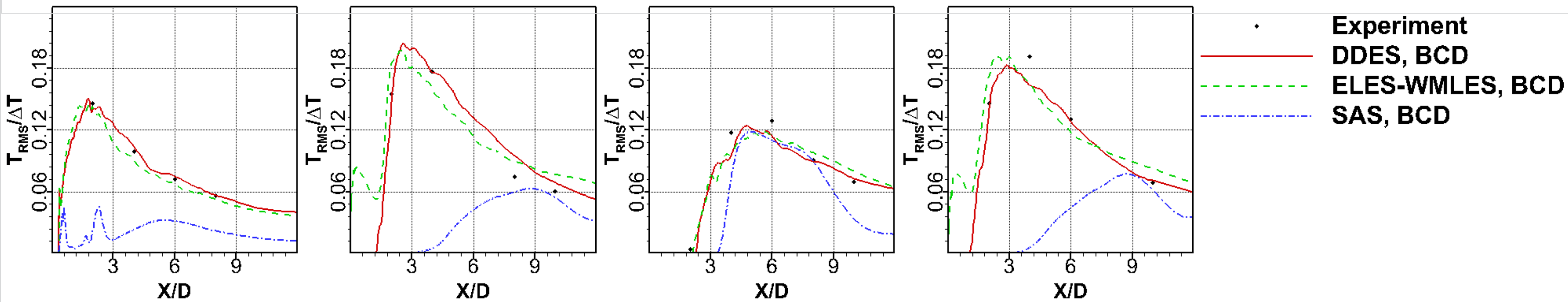
- **For SAS and DDES models, the results of the wall temperature are noticeably less accurate than those obtained with the ELES-WMLES approach**
- **The results for the RMS temperature indicate that all models predict RMS temperature fluctuations in good agreement with the data**

Mean and RMS Temperature Profiles for Different Models with BCD Scheme

Mean Temperature at Different Wall Sections (Top-Front-Bottom-Rear)



RMS Temperature at Different Wall Sections (Top-Front-Bottom-Rear)



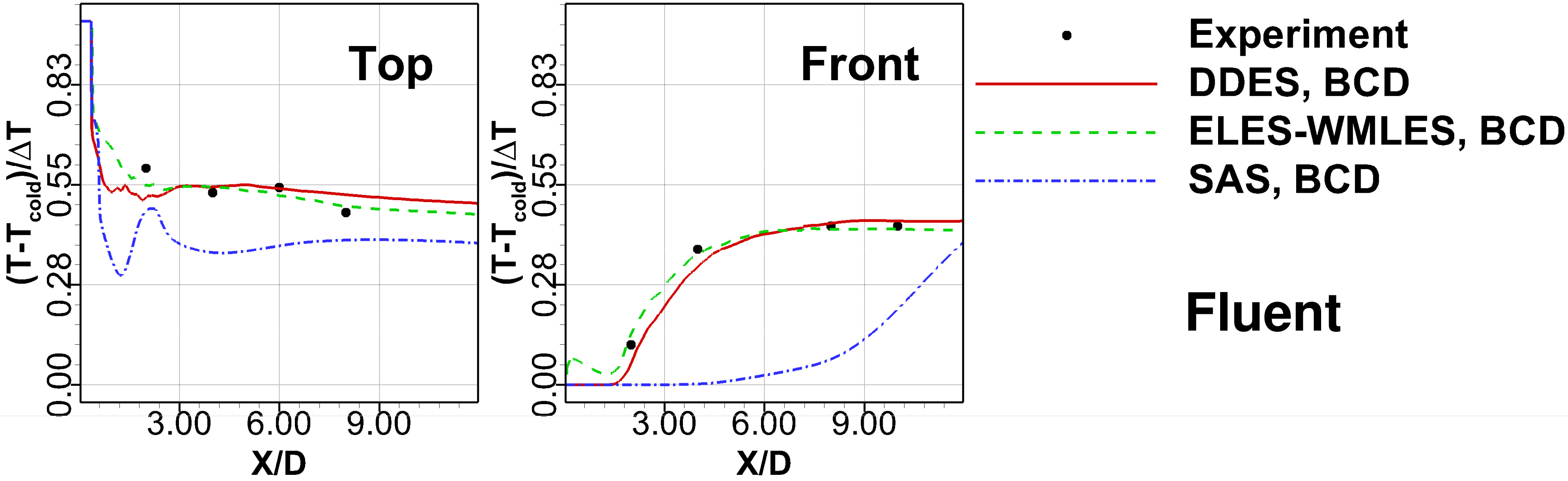
Influence of advection scheme is marginal for ELES-WMLES

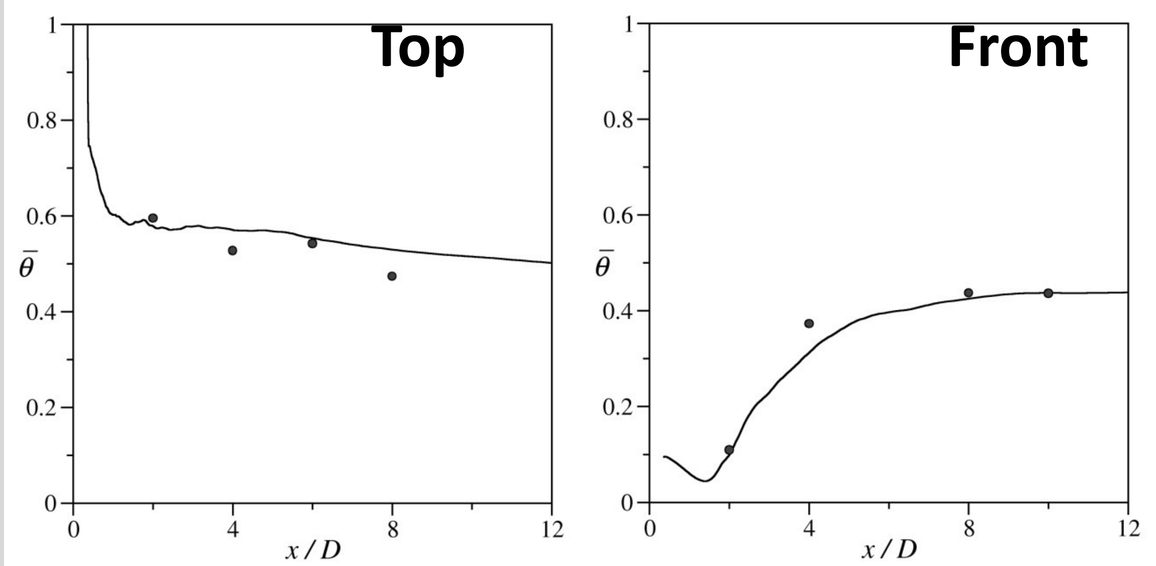
For SAS with BCD, the thermal mixing is predicted incorrectly

- **The wall temperature is significantly underestimated in all considered wall sections**
- **Similar tendencies, but less severe, are observed for DDES with BCD as well**

ANSYS

Mean T, top & front lines (0° & 90°)





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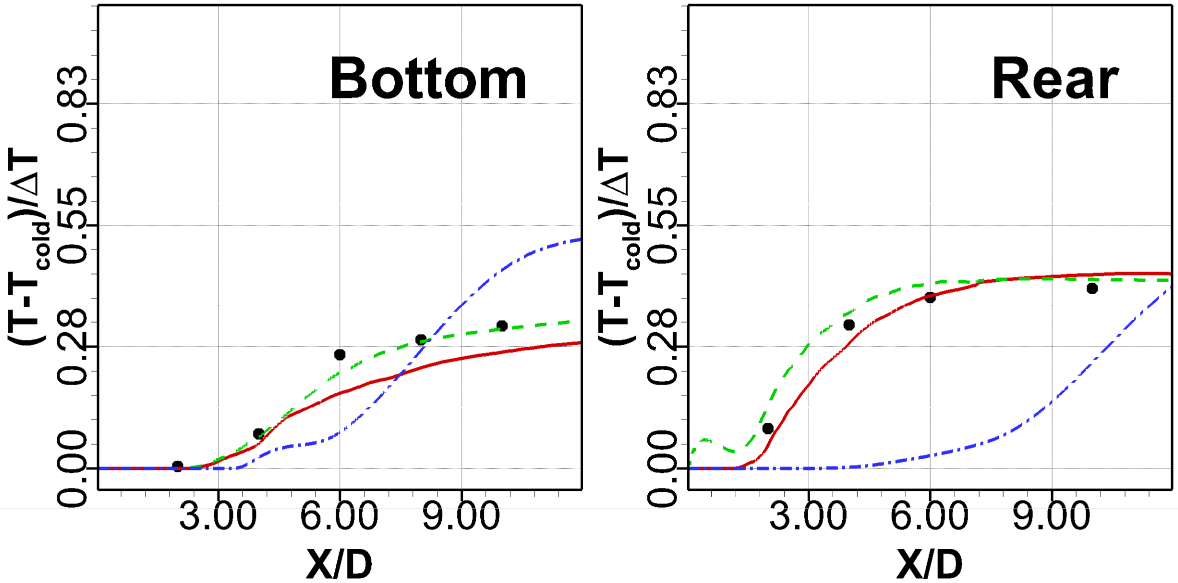
Experiment

Zonal LES, weak BCD

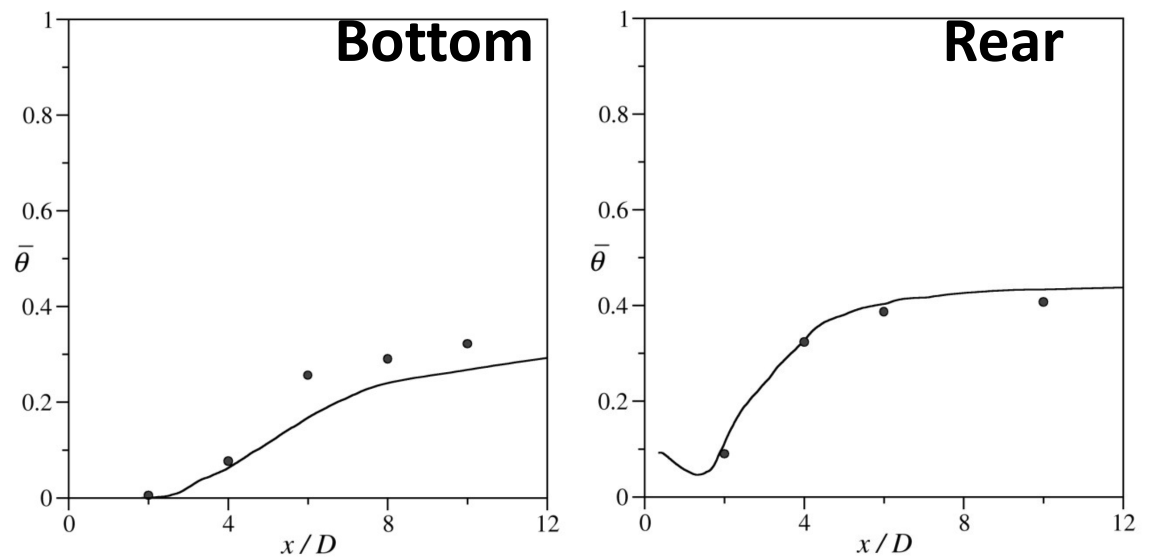
- Marginal influence of advection scheme for ELES
- SAS with BCD returns to URANS solution

Mean T, bottom & rear lines (180°&270°)



• Experiment
DDES, BCD
ELES-WMLES, BCD
SAS, BCD

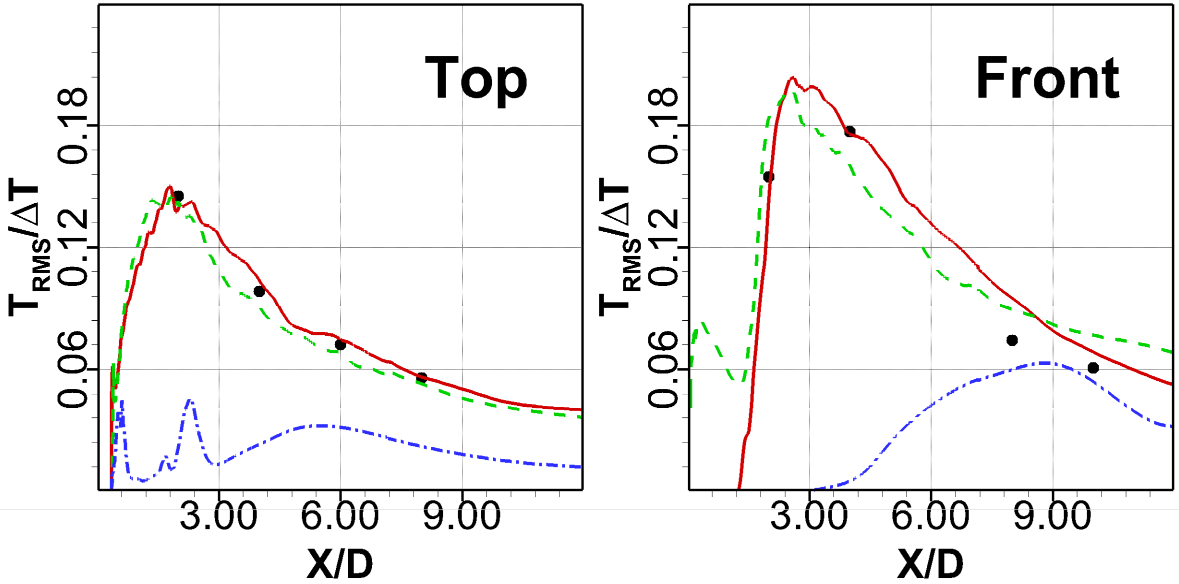
Fluent



CFX

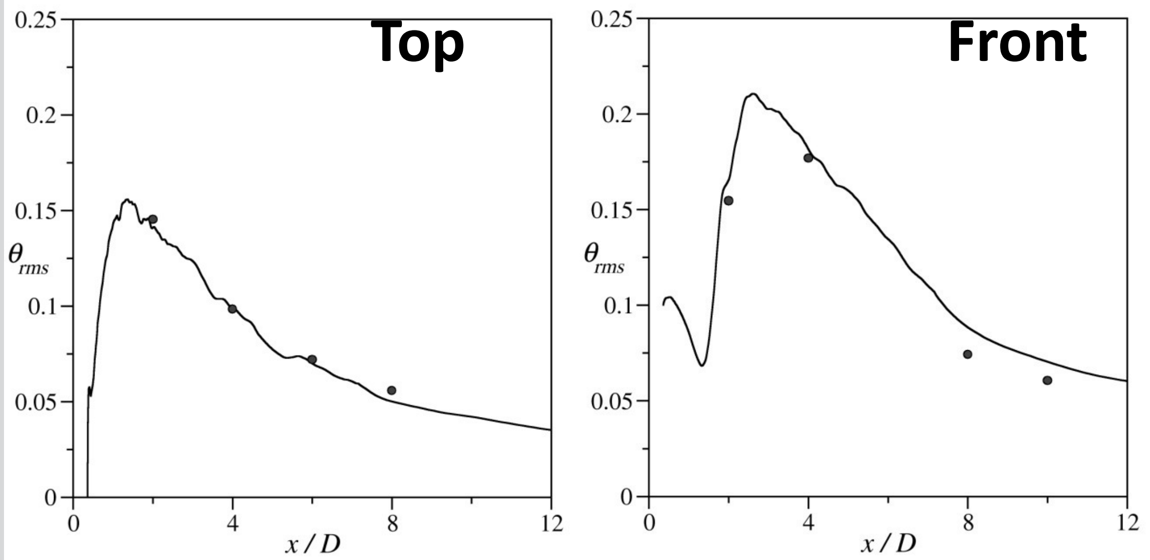
••• Experiment
Zonal LES, weak BCD

RMS T, top & front lines (0° & 90°)



- Experiment
- DDES, BCD
- ELES-WMLES, BCD
- SAS, BCD

Fluent

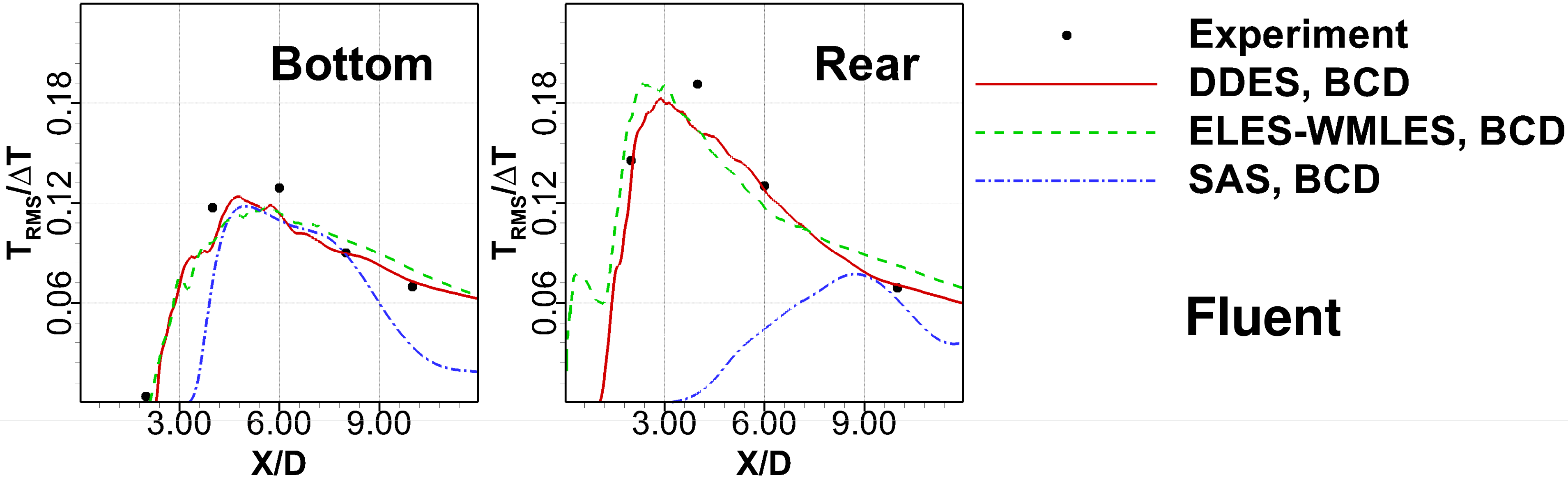


CFX

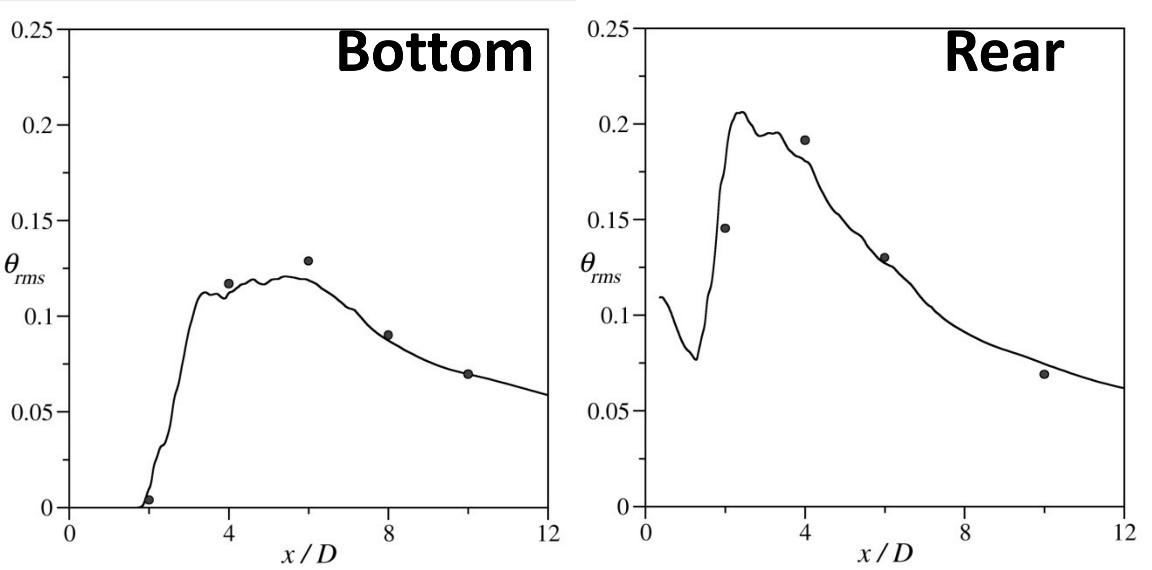
- ••• Experiment
- Zonal LES, weak BCD

T_{RMS} and turbulent mixing correctly predicted with DDES and ELES-WMLES/ZLES

RMS T, bottom & rear lines (180°&270°)



Fluent



CFX

Experiment

Zonal LES, weak BCD

Summary

- **OECD/NEA T-junction benchmark successfully investigated with ANSYS Fluent & ANSYS CFX**
- **All SRS models are able to accurately predict the mean and RMS velocity profiles, when used with low dissipation CD scheme**
  - **Weak local instability can lead to URANS solution with SAS and slightly more dissipative advection schemes (BCD, HiRes)**
  - **Can lead to delayed or not sufficient turbulent mixing**
  - **DDES model less sensitive to numerical settings**

Best SRS approaches:

✓ **Synthetic turbulence methods:**
Embedded LES in ANSYS FLUENT, Zonal LES in ANSYS CFX
✓ **Less dependent on the applied advection scheme**

- **Very good agreement with the experimental data for sensitive T_{mean} and T_{RMS} flow characteristics**

Questions ?