IVANNIKOV ISP RAS OPEN CONFERENCE

Large Eddy Simulation of turbulent circular jet using OpenFOAM

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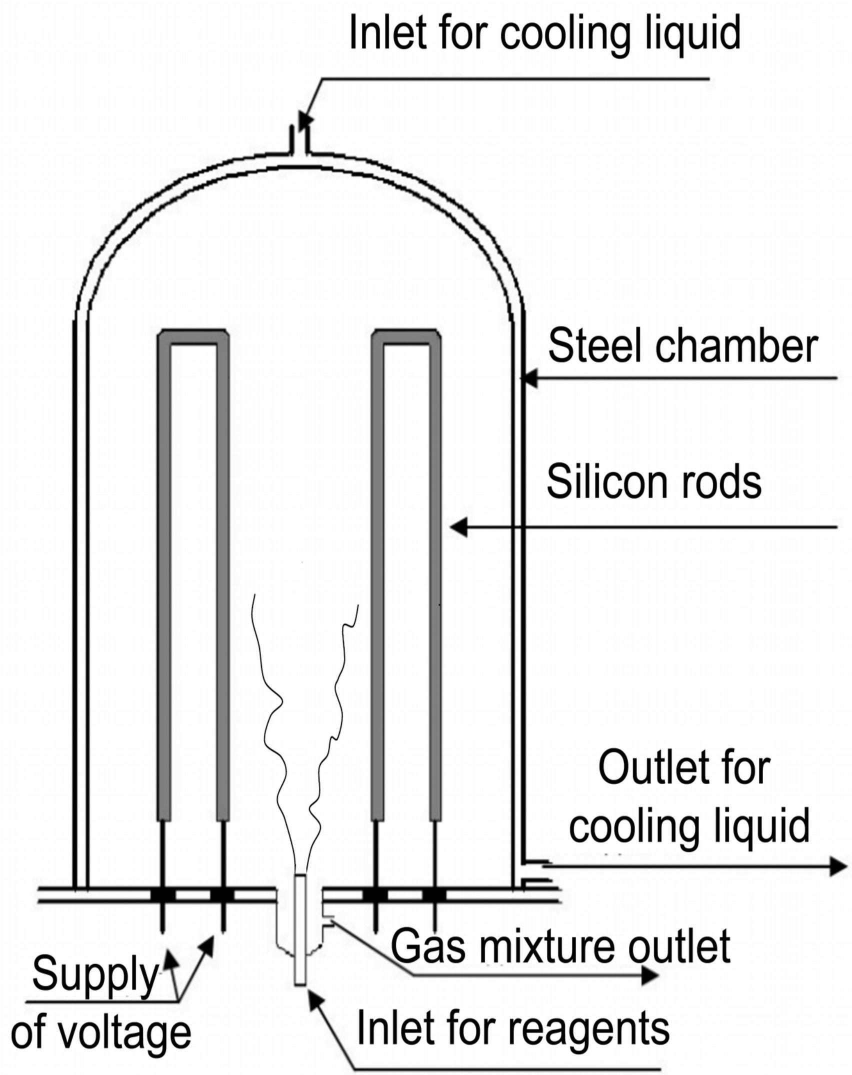
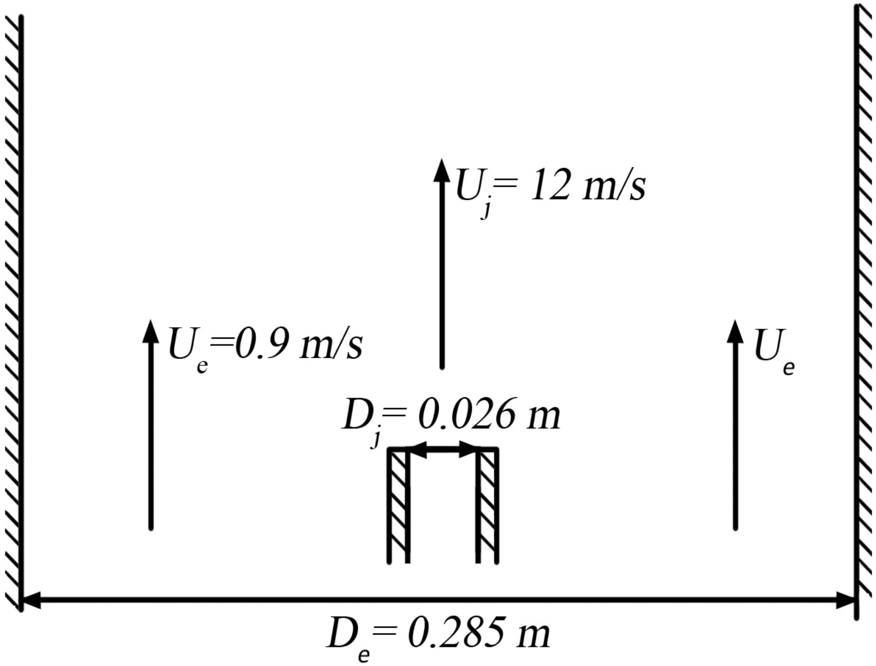
Motivation

- Siemens technology (based on chemical vapor deposition) is widely used for polysilicon production
- Silicon containing gas mixture is supplied by turbulent jet
- Heat exchange and mass transport are determined by turbulent fluctuations
- Numerical modeling is required to improve reactor characteristics



Polysilicon deposition reactor

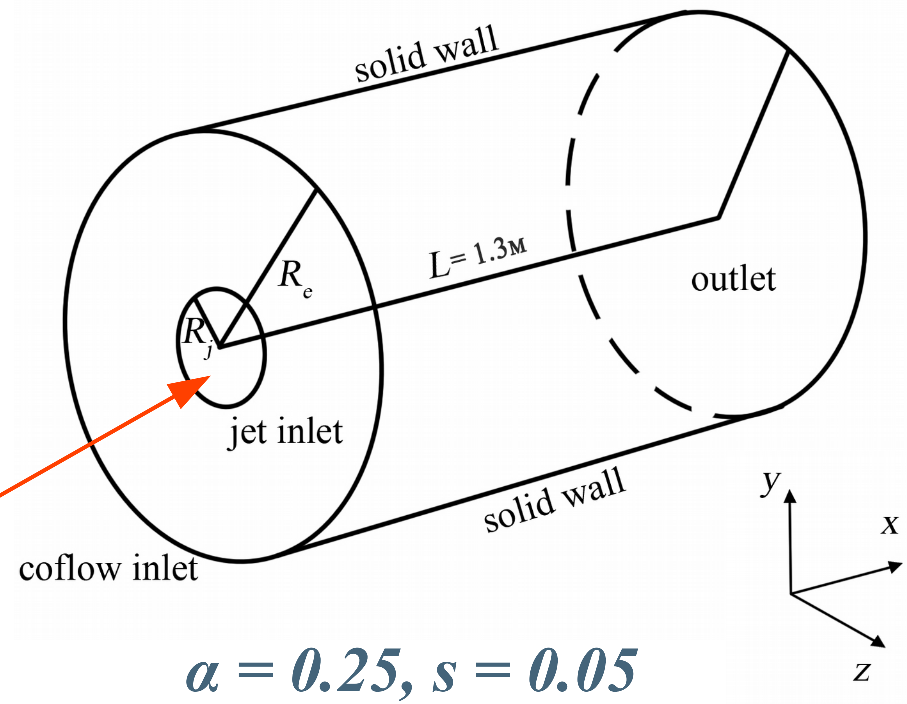
The experimental set-up and computational domain



$$Re = D_j U_j / \nu = 21000$$

$$m = U_e / U_j = 0.075$$

T. Djeridane, M. Amielh, F. Anselmet, and L. Fulachier, "Velocity nearfield of variable density turbulent jets", International Journal of Heat and Mass Transfer 39 (1996) 2149-2164



Turbulent Inlet boundary condition

$$U^n = (1\text{-}\alpha) U^{n-1} + \alpha\,(U_j + r \cdot s \cdot C \cdot U_j)$$

$$\alpha = 0.25,\ s = 0.05$$

Mathematical model and numerical method

1. Models
   - LES WALE model
   - Implicit LES (ILES) approach
2. Codes
   - OpenFOAM (PIMPLE solver from incompressible group)
   - SINF/Flag-S (original version of the implicit fractional-step method to advance in physical time)
3. Numerical schemes: LUST, QUICK, Linear Upwind, Linear
4. The approximation of the time derivative was carried out with the second-order scheme “backward”

Mesh

1. Original mesh: 1.3 mln cells

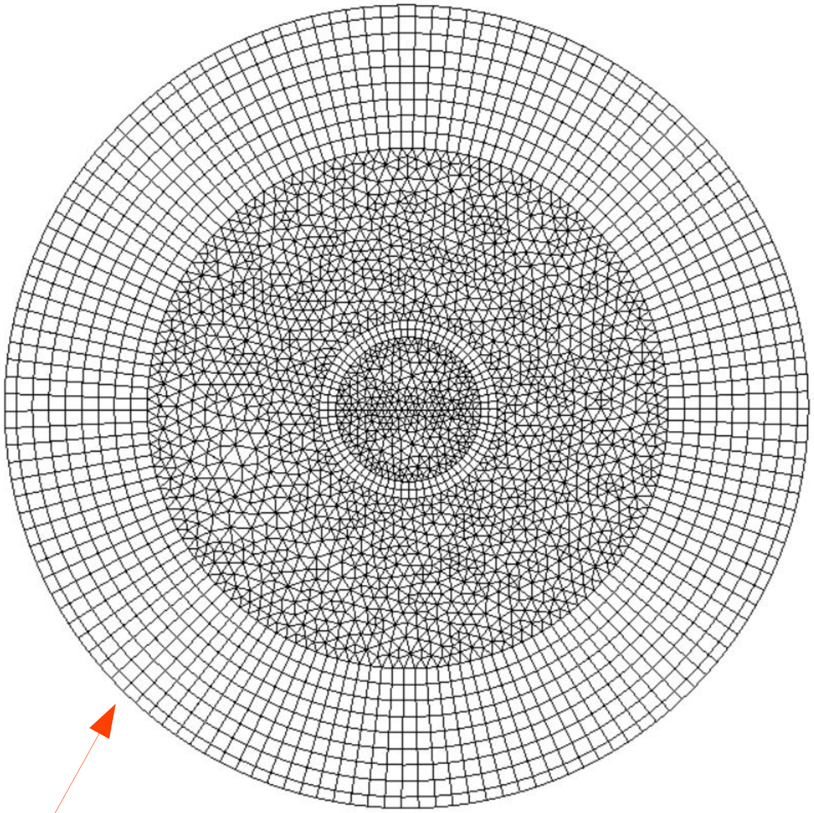
Typical cell size ~ 0.004 m, 22 cells/D_j

2. Fine mesh: 11 mln cells

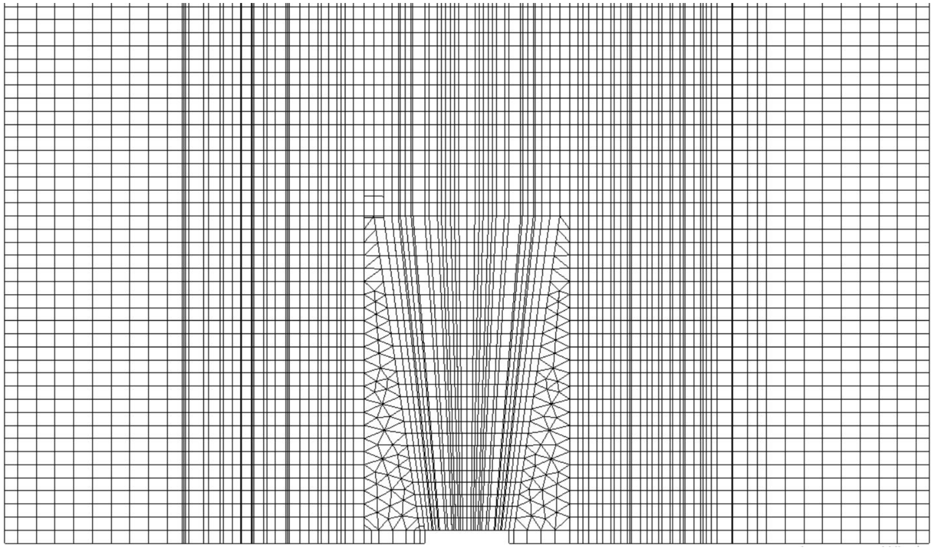
Typical cell size ~ 0.002 m, 40 cells/D_j

3. Coarse mesh: 0.2 mln cells

Typical cell size ~ 0.08 m, 12 cells/D_j

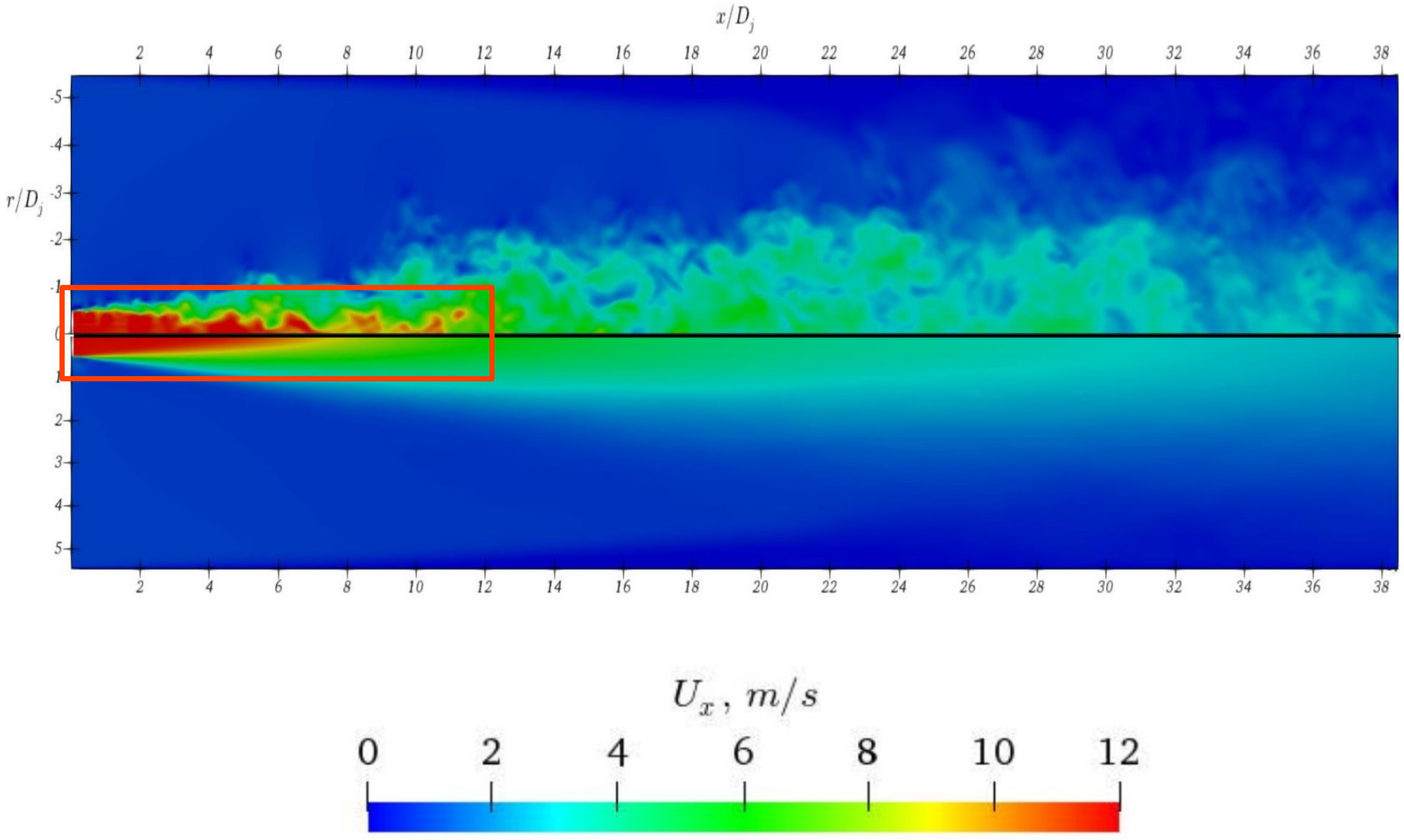


cross section near outlet

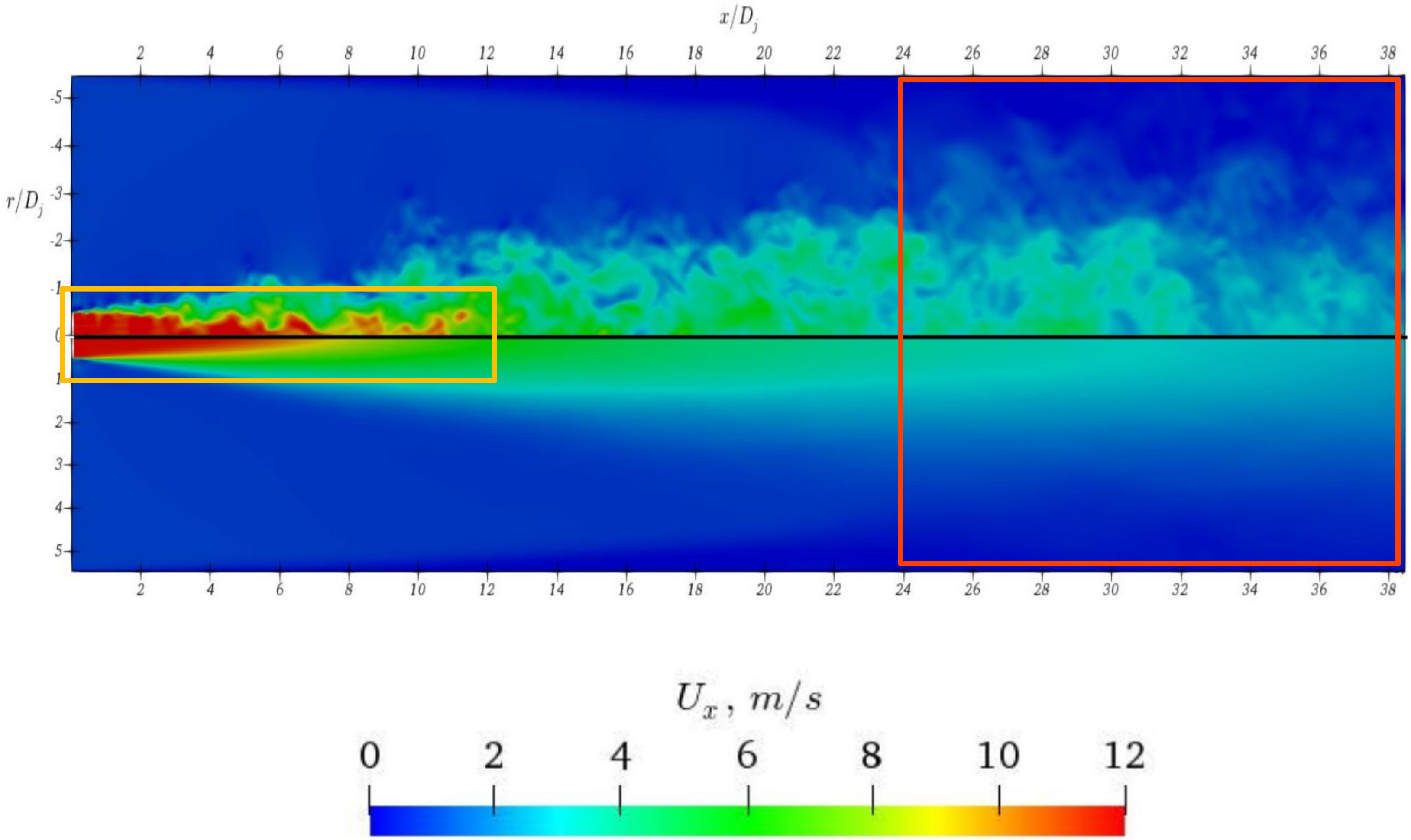


longitudinal section near inlet

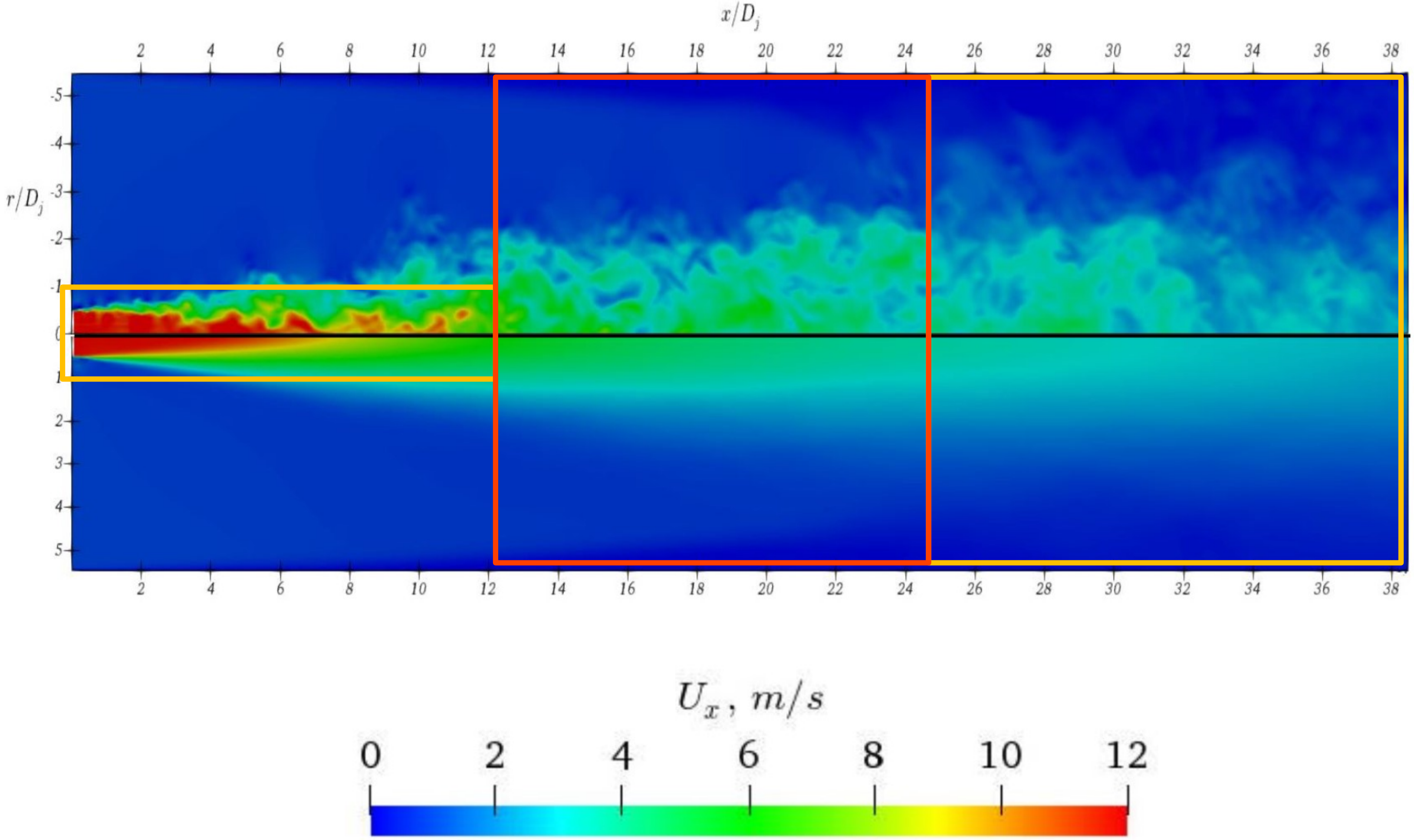
Instantaneous and averaged distributions of velocity magnitude



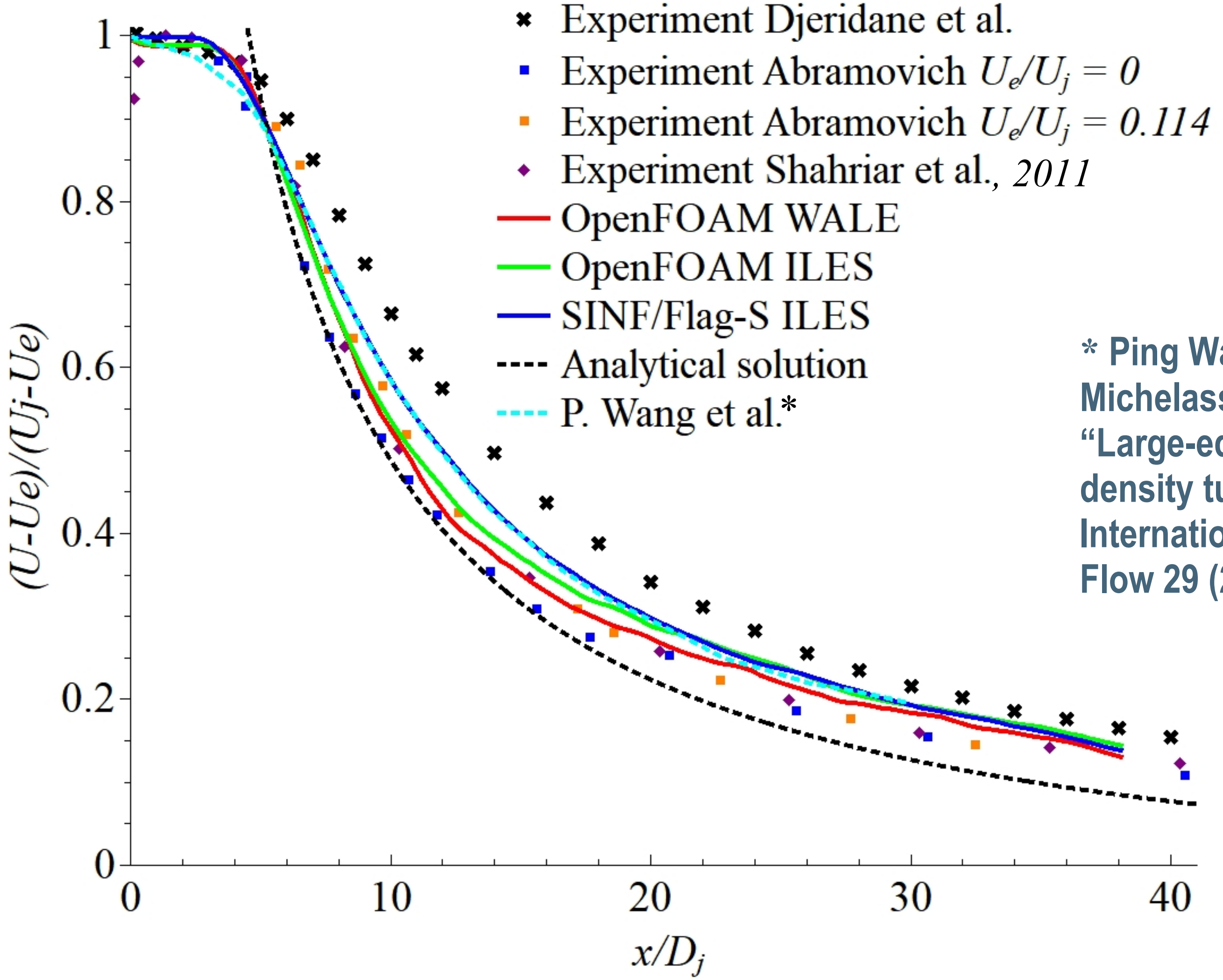
Instantaneous and averaged distributions of velocity magnitude



Instantaneous and averaged distributions of velocity magnitude



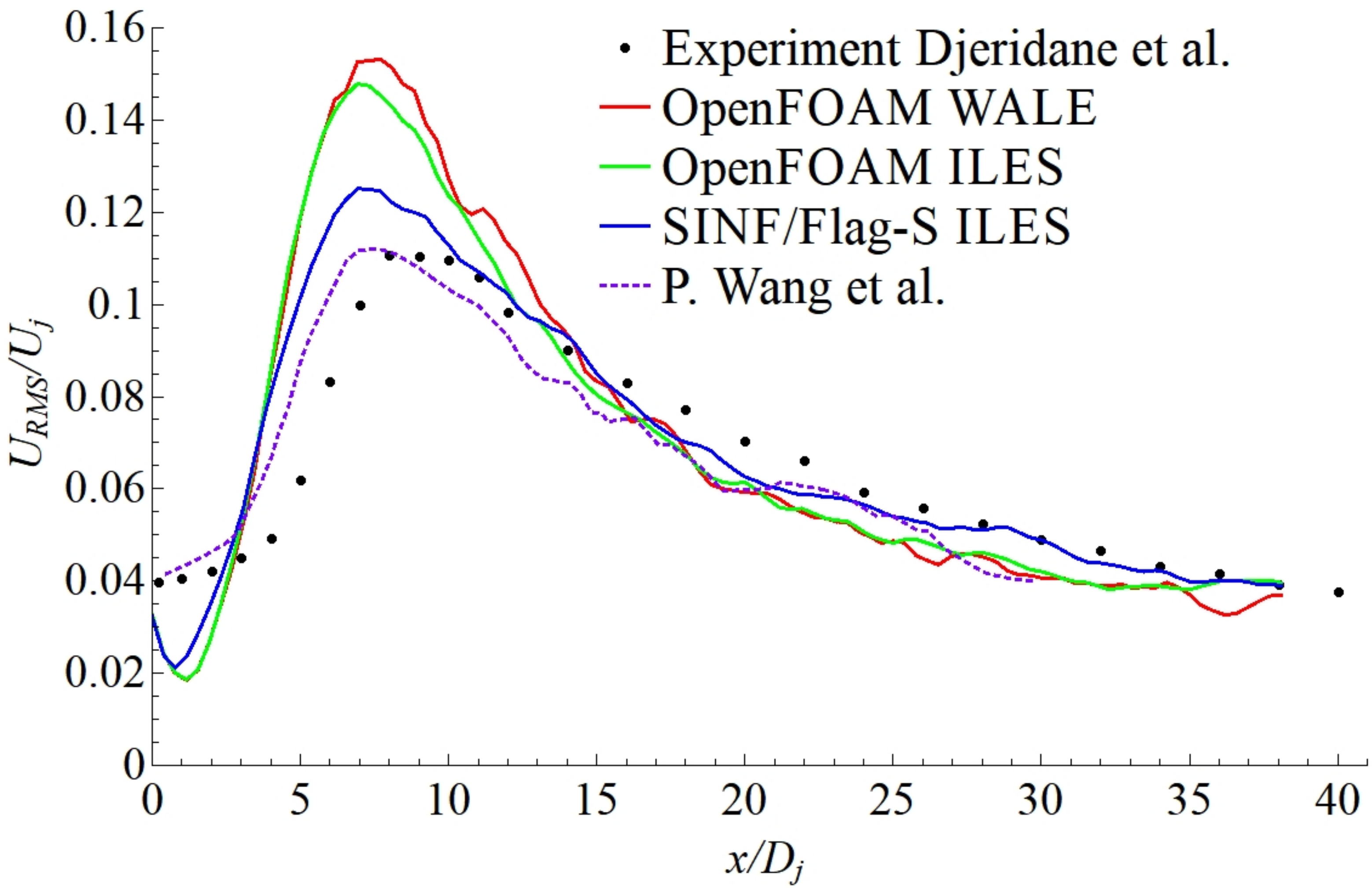
Comparison with the experimental data



* Ping Wang, Jochen Fröhlich, Vittorio Michelassi, Wolfgang Rodi "Large-eddy simulation of variable-density turbulent axisymmetric jets", International Journal of Heat and Fluid Flow 29 (2008) 654–664

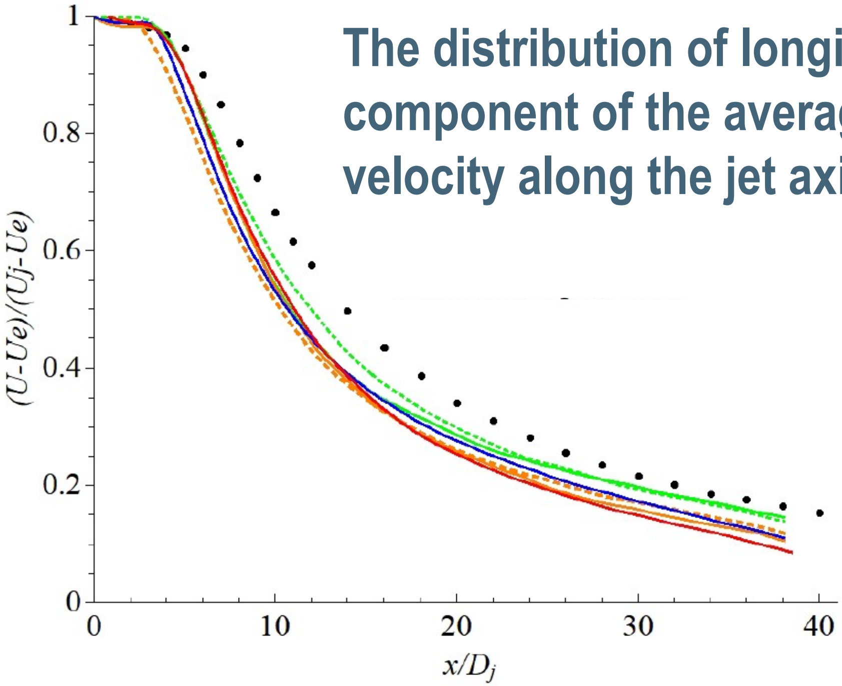
The distribution of longitudinal component of the averaged velocity along the jet axis

Comparison with the experimental data



The distribution of the RMS-fluctuation of longitudinal velocity component along the jet axis

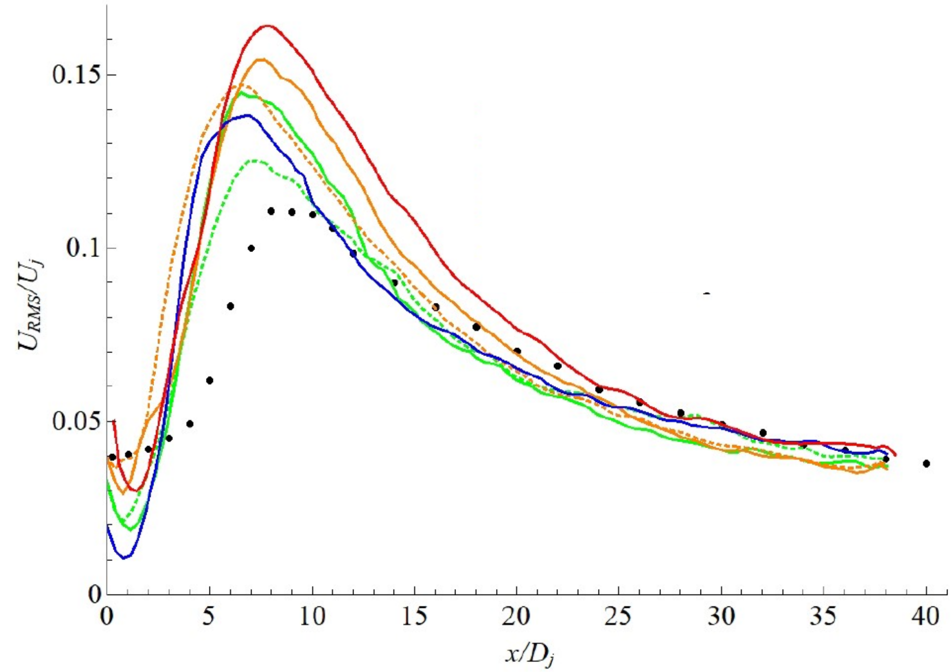
Grid sensitivity



The distribution of longitudinal component of the averaged velocity along the jet axis

- Experiment Djeridane et al.
- Fine mesh OpenFOAM
- Fine mesh SINF/Flag-S
- Original mesh OpenFOAM
- Original mesh SINF/Flag-S
- Combined mesh OpenFOAM
- Coarse mesh OpenFOAM

$$\Delta\tau = \Delta t U_j / D_j = 0.11$$

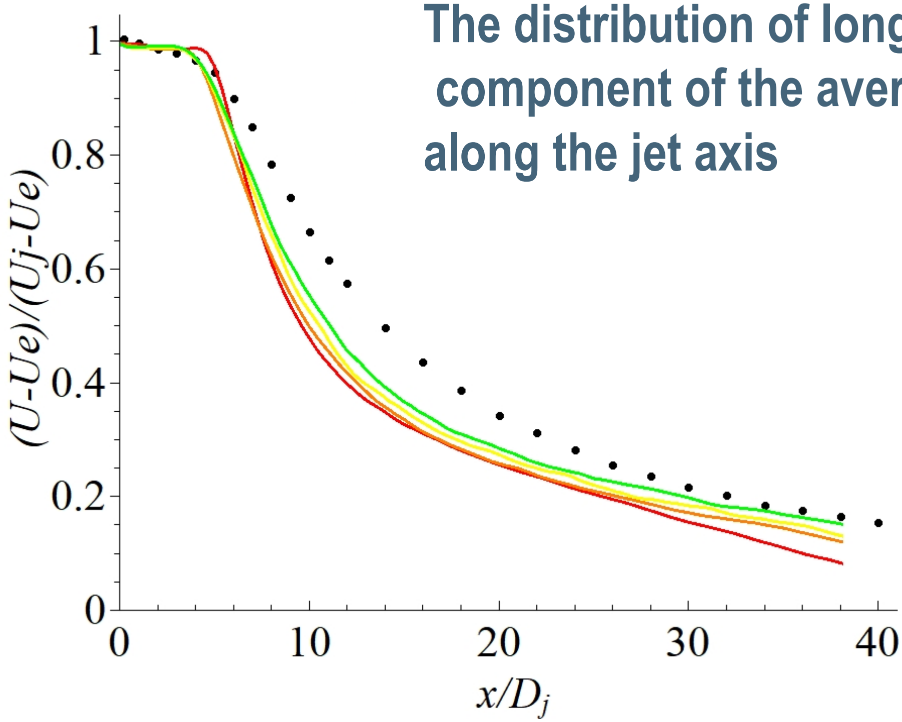


The distribution of the RMS-fluctuation of longitudinal velocity component along the jet axis

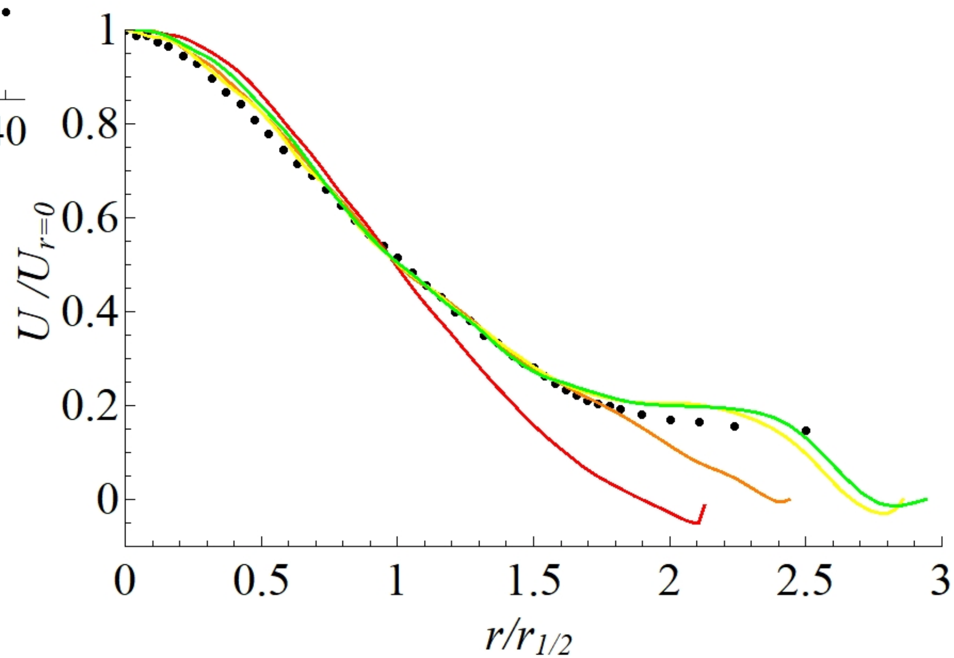
Influence of time step

Fine mesh

The distribution of longitudinal component of the averaged velocity along the jet axis



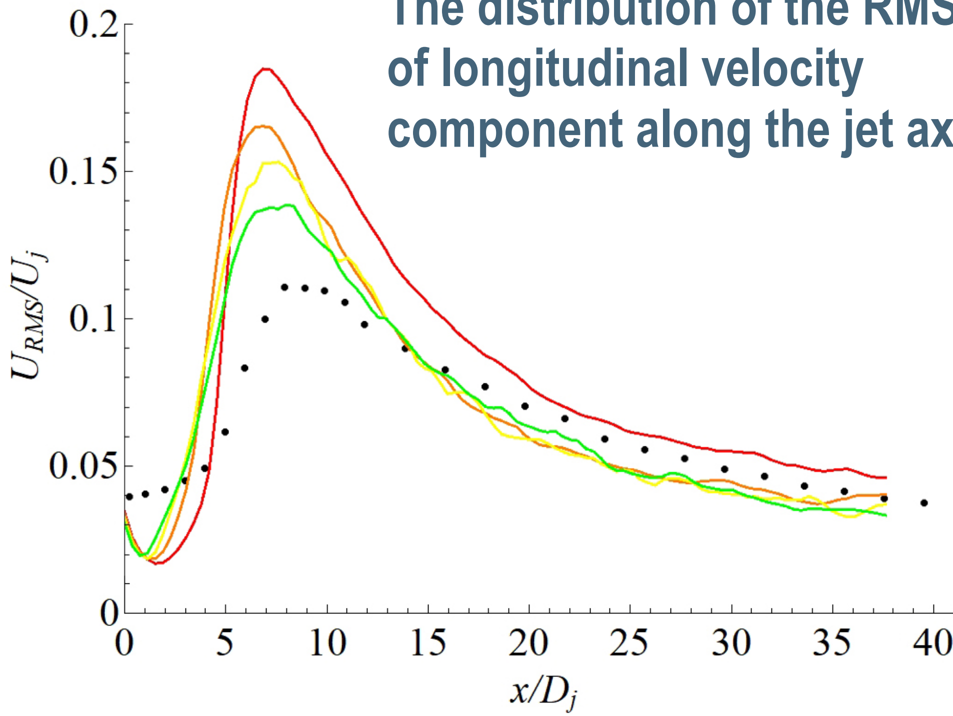
The distribution of longitudinal component of the averaged velocity along the radius in the section $x/D_j = 20$



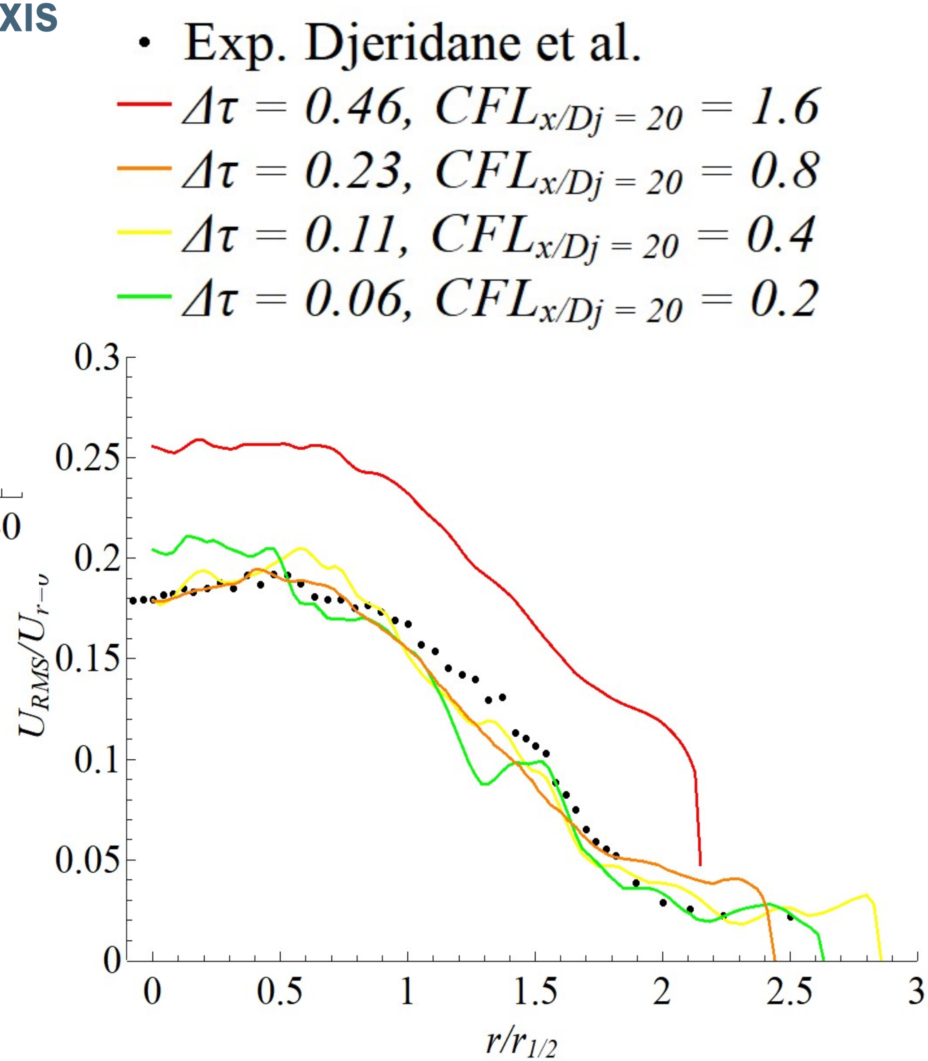
$$\Delta\tau = \Delta t U_j / D_j = 0.11$$

Influence of time step

The distribution of the RMS-fluctuation of longitudinal velocity component along the jet axis

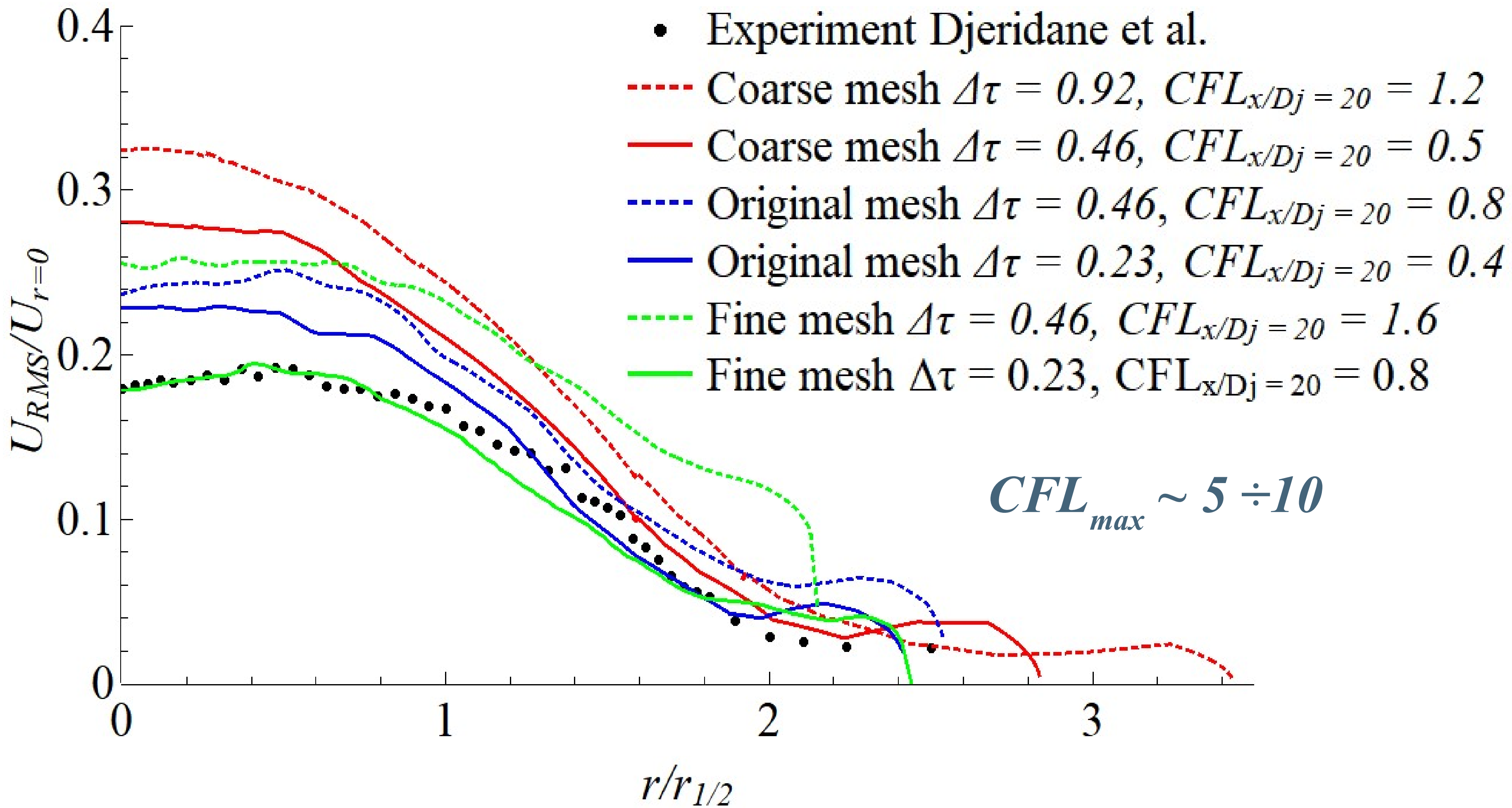


Fine mesh



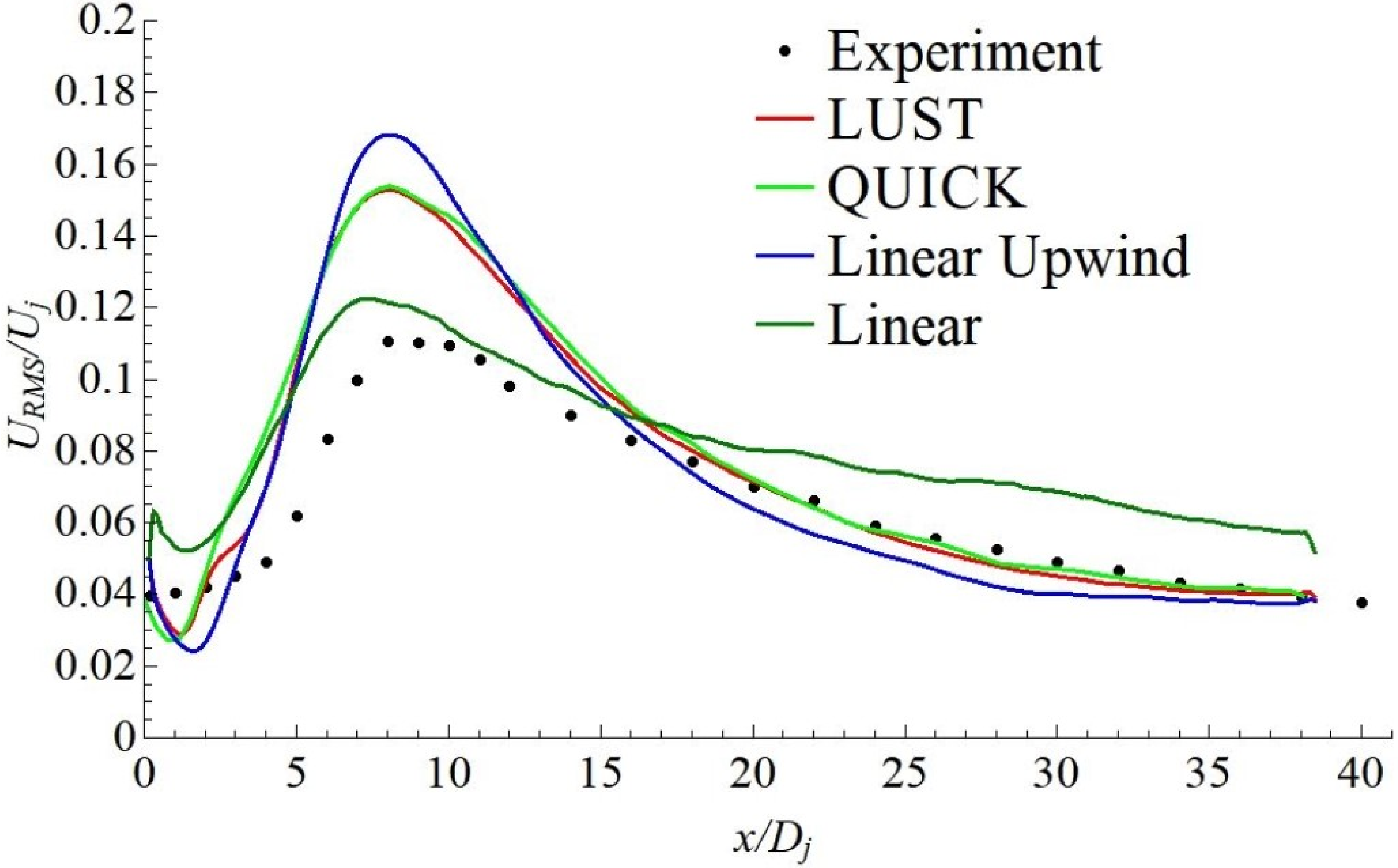
The distribution of the RMS-fluctuation of longitudinal velocity component along the radius in the section $x/D_j = 20$

Courant number sensitivity



The distribution of the RMS-fluctuation of longitudinal velocity component along the radius in the section $x/D_j = 20$

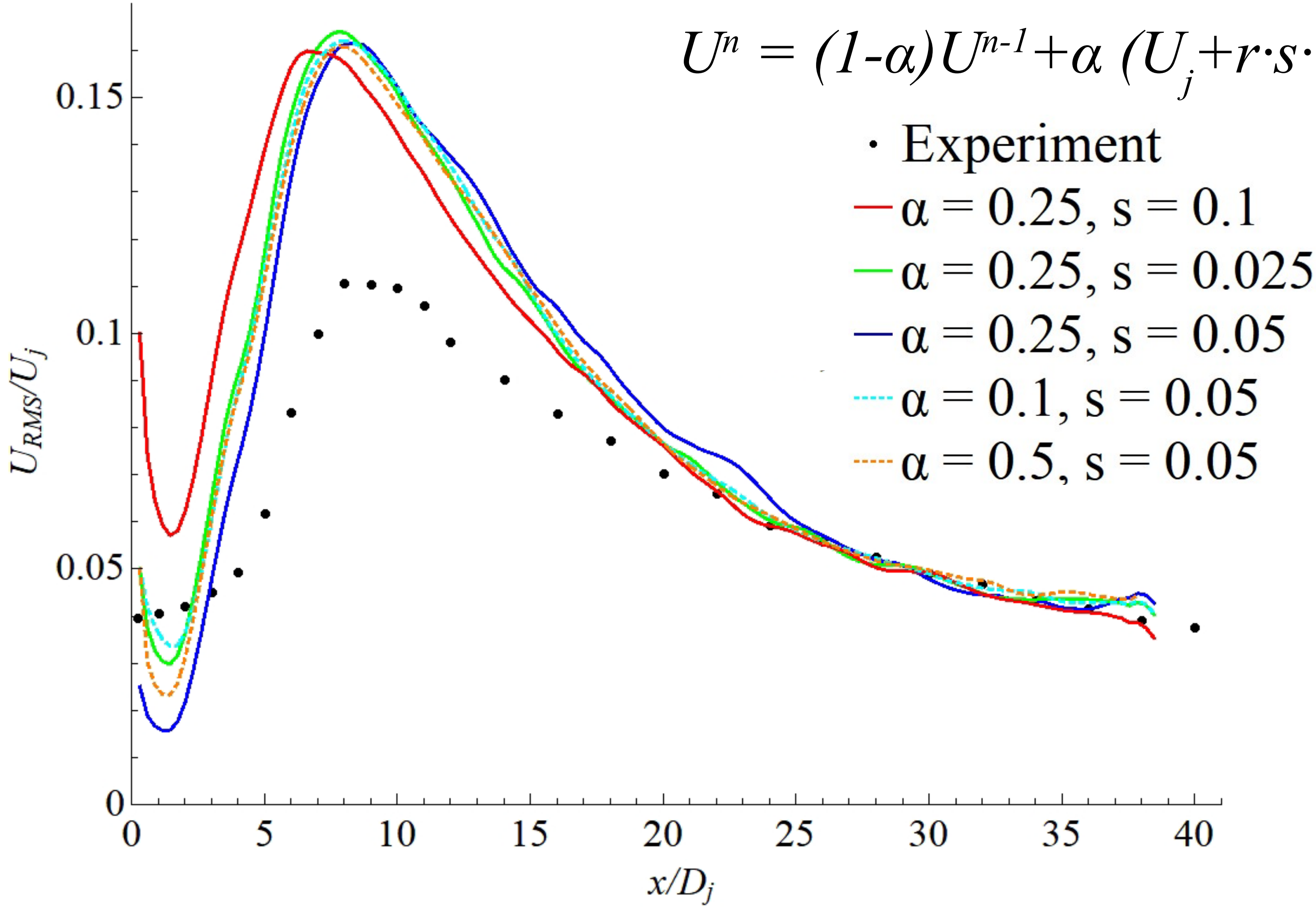
Influence of numerical scheme



The distribution of the RMS-fluctuation of longitudinal velocity component along the jet axis

Influence of synthetic generator parameters

$$U^n = (1-\alpha)U^{n-1} + \alpha\,(U_j + r\cdot s\cdot C\cdot U_j)$$



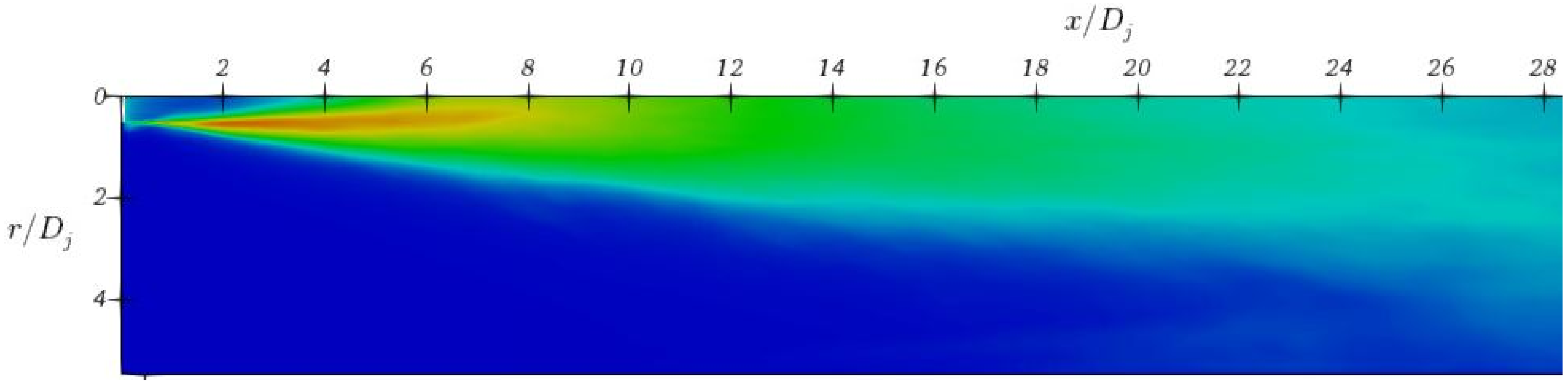
The distribution of the RMS-fluctuation of longitudinal velocity component along the jet axis

Conclusion

- For accurate modeling of averaged characteristics it is recommended to use original (22 cells/D_j) or coarse (12 cells/D_j) mesh
- For accurate modeling of fluctuation characteristics it is recommended to use fine (40 cells/D_j) mesh
- It is possible to use time step corresponding $CFL_{max} \sim 10$, but it is desirable to achieve $CFL < 1$ at the main jet region
- Results obtained by LES WALE and ILES are almost similar
- Influence of considered numerical schemes on the solution is quite small, except linear scheme, which gives non-physical pulsations
- The LUST or QUICK scheme is recommended to use in LES
- The small solution sensitivity to the synthetic generator parameters was also observed

The longitudinal component of the RMS-fluctuation velocity field for solutions obtained by OpenFOAM (a) and SINF/Flag-s (b)

a)



b)