A Novel Rough Wall Boundary Condition for LES of high Reynolds Number Flows

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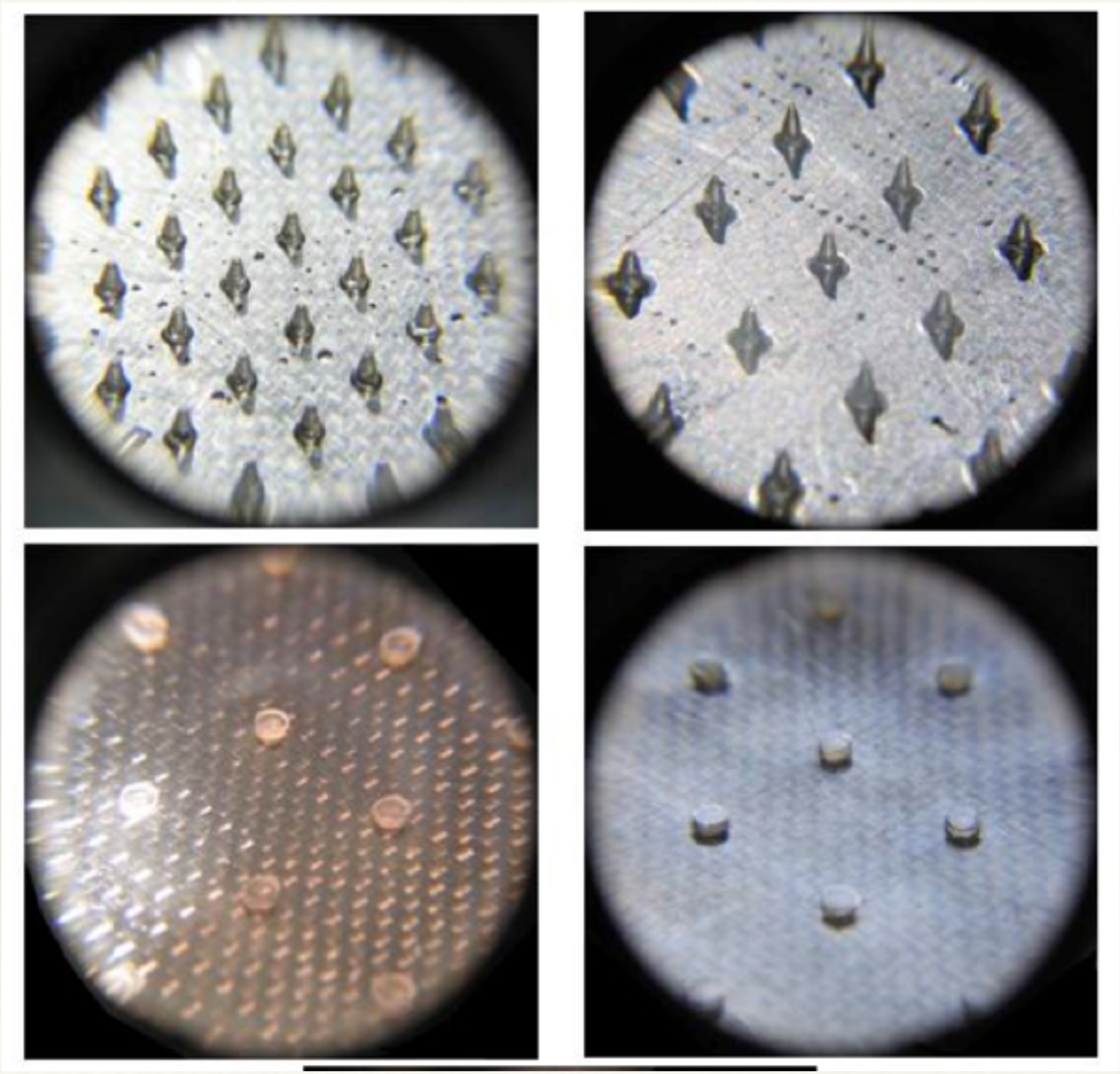
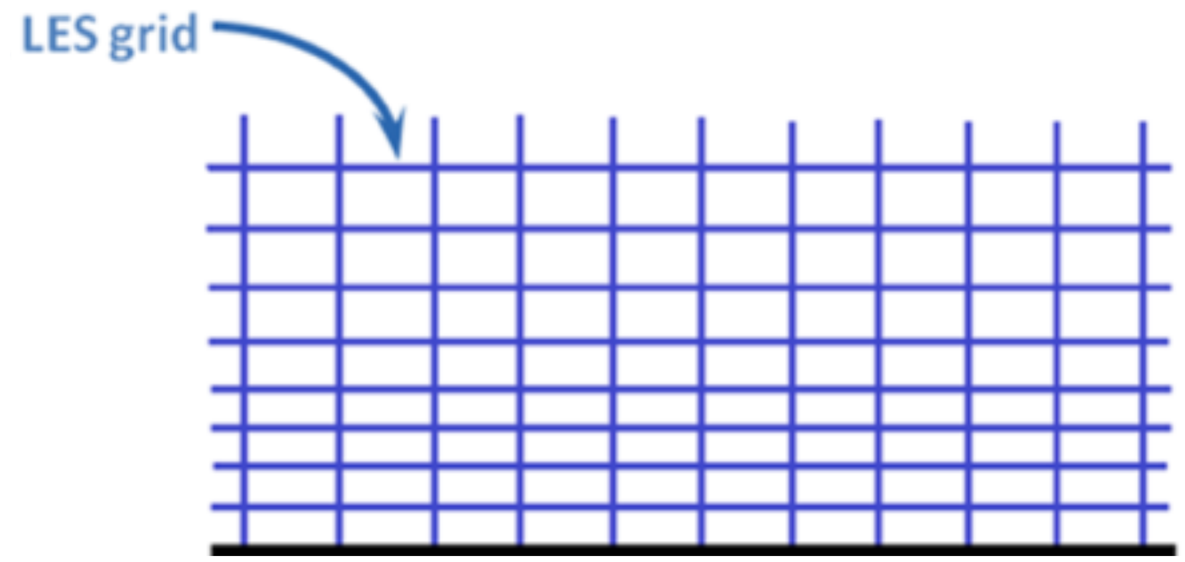
Outline



- Methodology
- Implementations
- Results

Methodology



Methodology—wall modeling

- For Large Eddy Simulation (LES) at high Reynolds number, wall shear stress should be modeled.

- The total wall shear stress is composed of the "smooth" part and the "rough" part:

$$\tau_{total} = \tau_{smooth} + \tau_{rough}$$

Methodology—wall modeling

- Smooth wall modeling
  - Obtain flow velocity U by interpolating from LES mesh.
  - Solve boundary layer equation in the wall-modeling mesh:

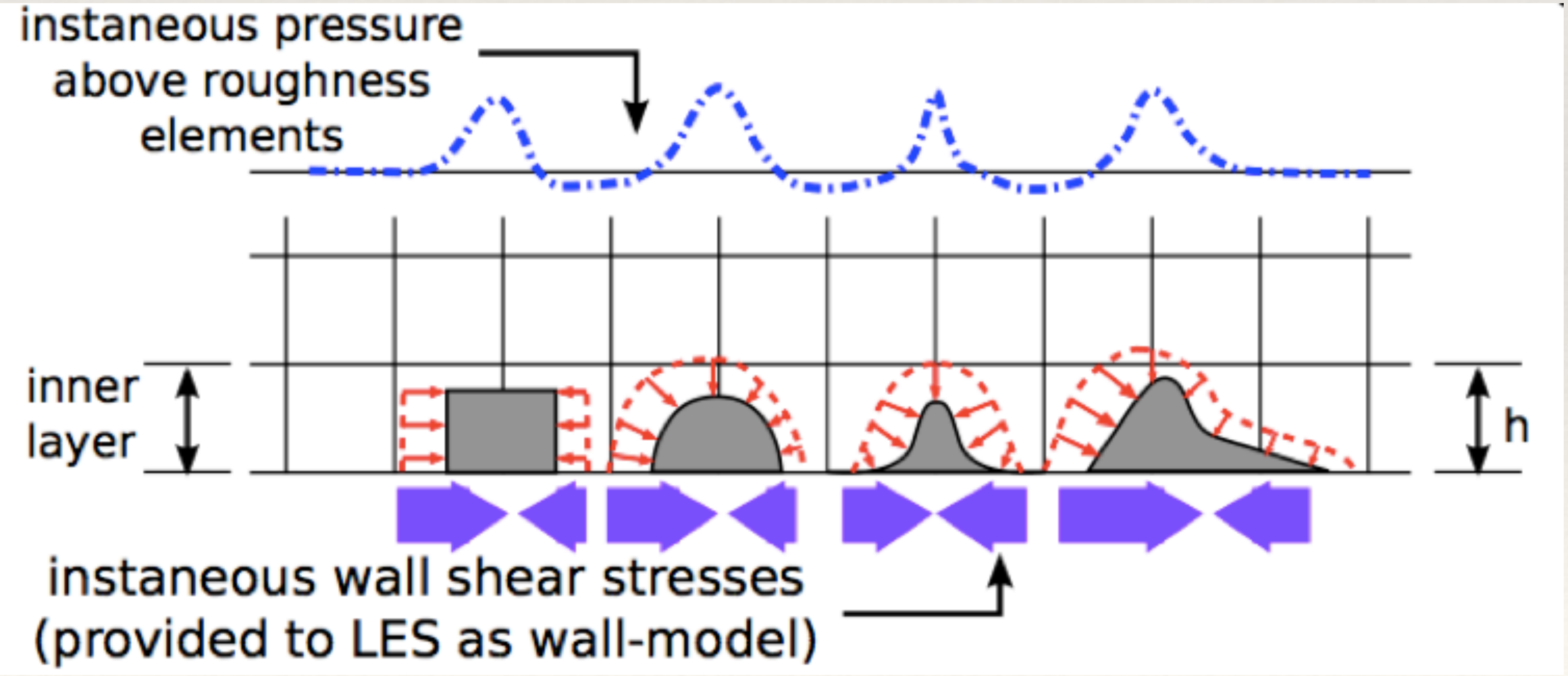
$$\frac{\mathrm{d}}{\mathrm{d}\eta}\left((\mu+\mu_{t,wm})\frac{\mathrm{d}u_{\|}}{\mathrm{d}\eta}\right) = 0\,,$$

$$\mu_{t,wm} = \kappa\eta\sqrt{\rho\tau_w}\left[1-\exp\left(-\frac{\eta^+}{A^+}\right)\right]^2\,, \quad \text{with } A^+ = 17,\ \kappa = 0.41\,.$$

  - Obtain the shear stress τ_{smooth} from the velocity field in the wall-modeling mesh.

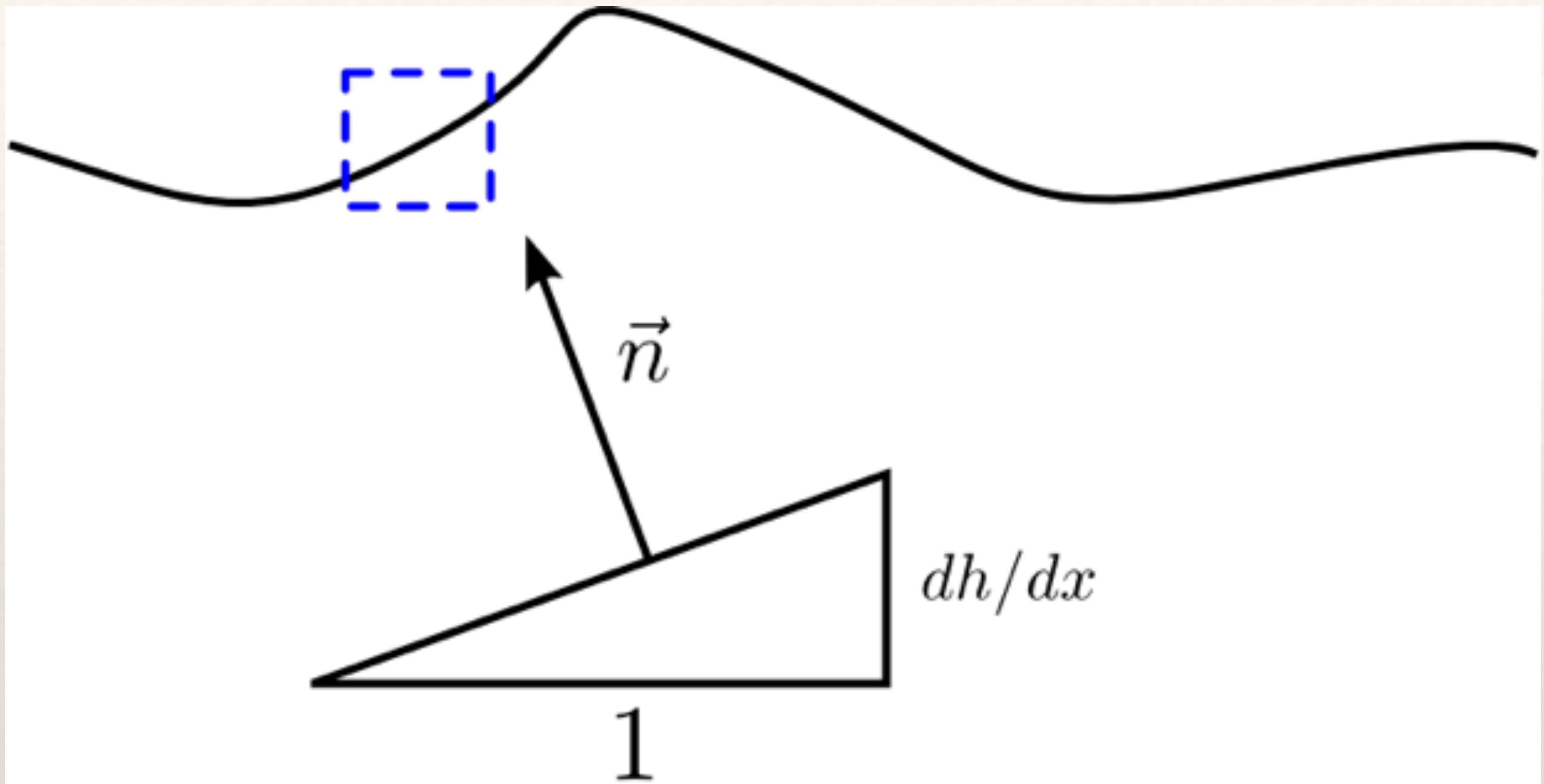
Methodology—wall modeling

- Rough wall modeling
  - Elevation of the elements expressed in h on WM mesh.
  - Obtain flow pressure P by interpolating from LES mesh.
  - Obtain the force induced by the pressure on each element.



Methodology—wall modeling

- Rough wall modeling



We have:

$$\vec{n} = [-dh/dx, 1, -dh/dz]/dS$$

$$d\vec{F} = -p \cdot \vec{n} dS$$

Finally, $d\vec{F} = -p \cdot [dh/dx, -1, dh/dz]$

$$\vec{\tau}_{rough} = -p/A \cdot [dh/dx, -1, dh/dz]$$

  - Obtain the shear stress τ_{rough} due to roughness.

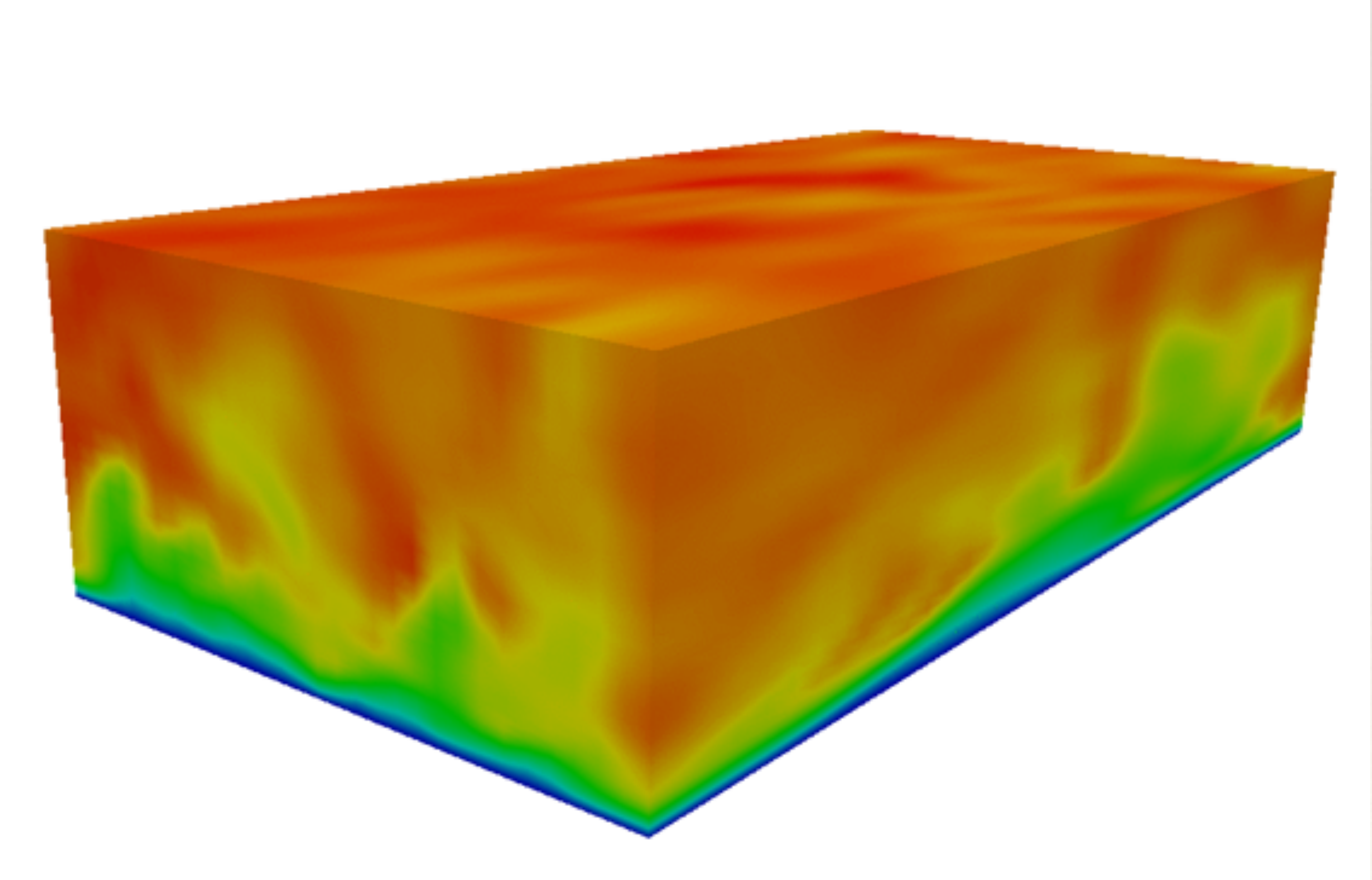
Code Implementations

- OpenFOAM
  - open-source
  - C++ tool box

- OpenFOAM solver *pisoFoam*
  - Incompressible solver
  - PISO algorithm

Numerical tests

- Smooth wall modeling test
  - High Reynolds number, channel flow.
- Rough wall modeling test
  - High Reynolds number, channel flow. Roughness elements at bottom.



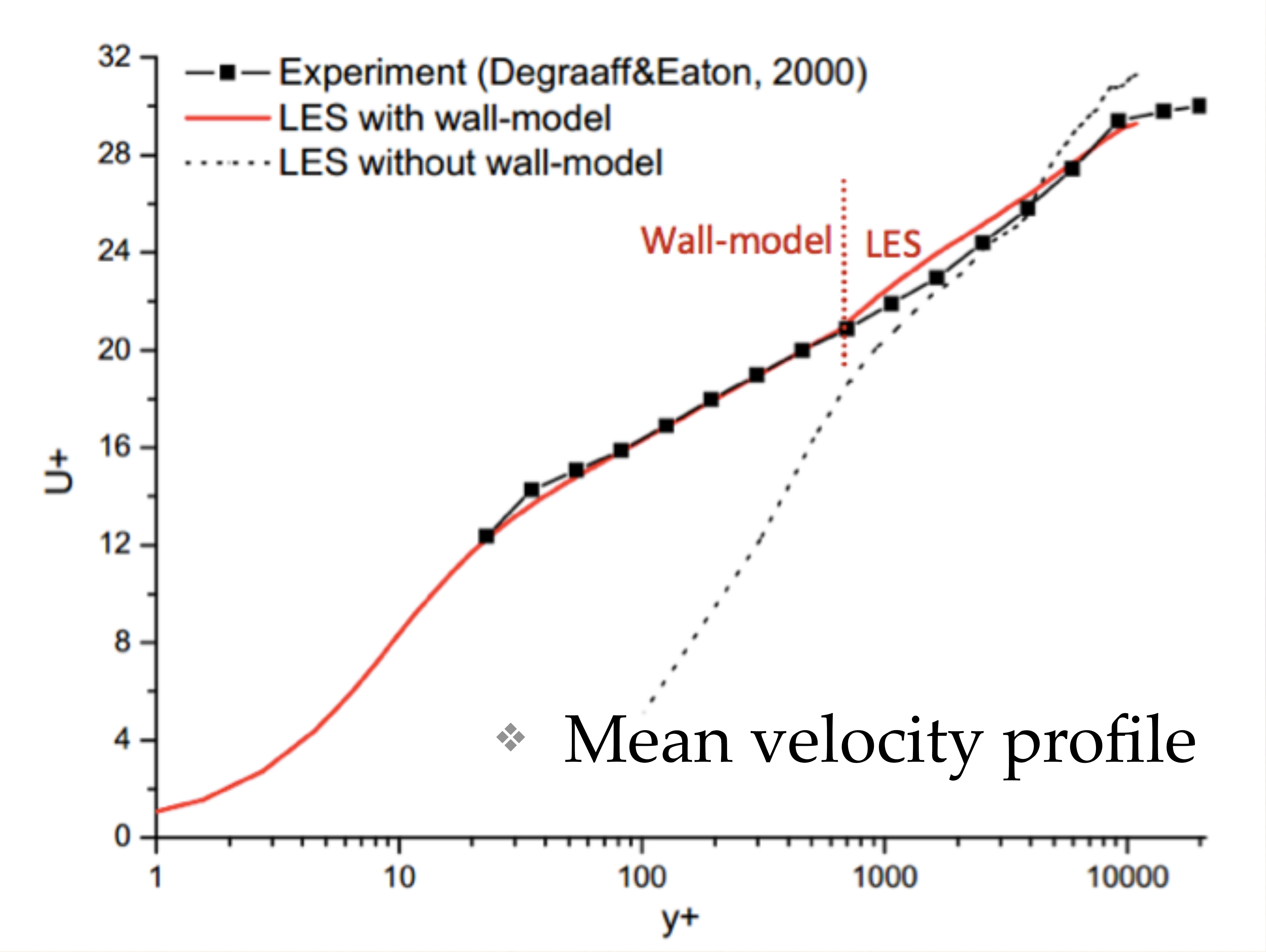
Numerical tests

- Case setup: smooth wall modeling test.

Reynolds number (Re	300,000	domain size	0.42 m × 0.04 m × 0.18 m
average flow velocity	17.15 m/s	CFD cells	240 × 31 × 100
y+	100	computational cost	3,200 CPU hours

Numerical tests

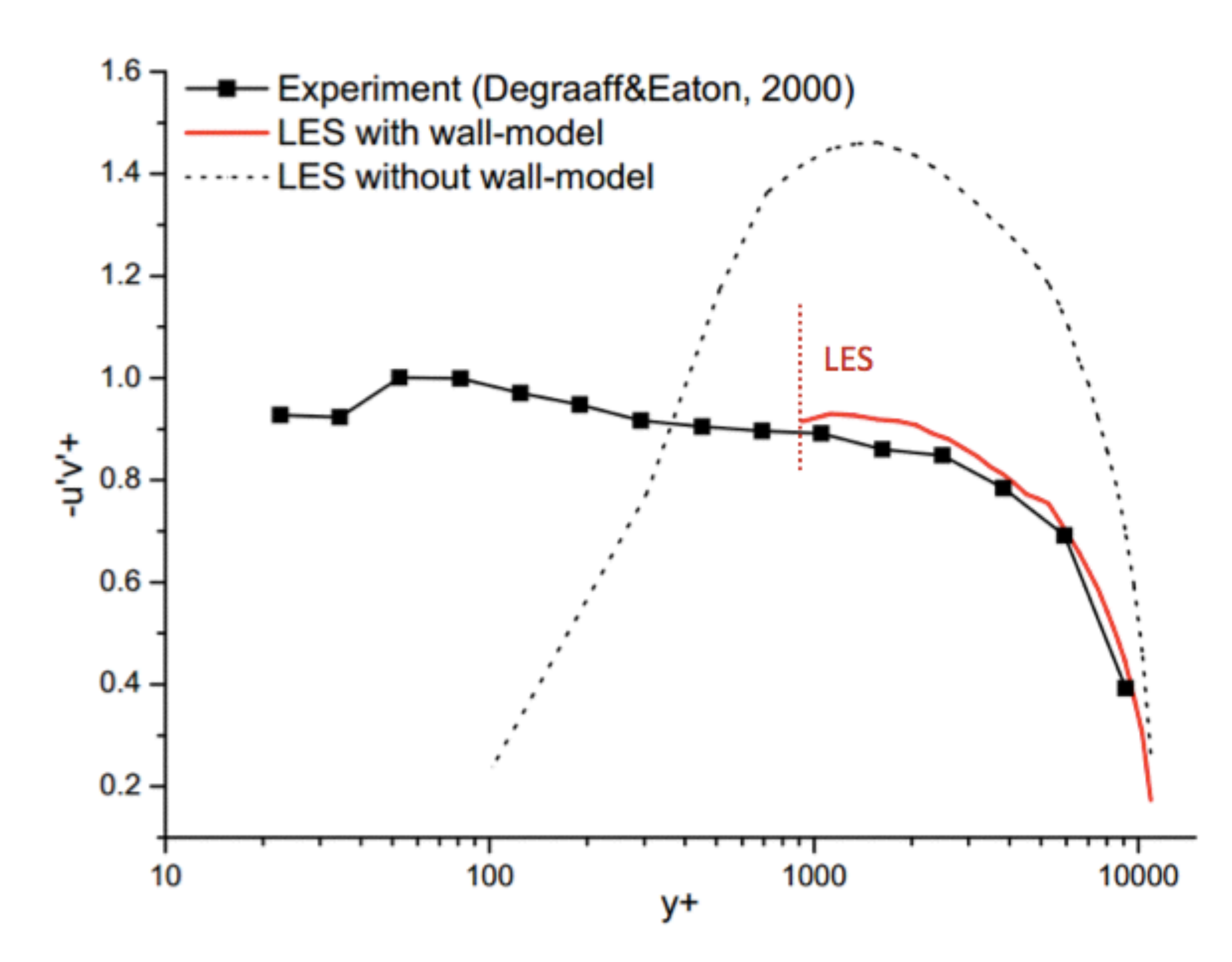
- Smooth wall modeling test (Re_{bulk} = 300,000)



- Mean velocity profile

Numerical tests

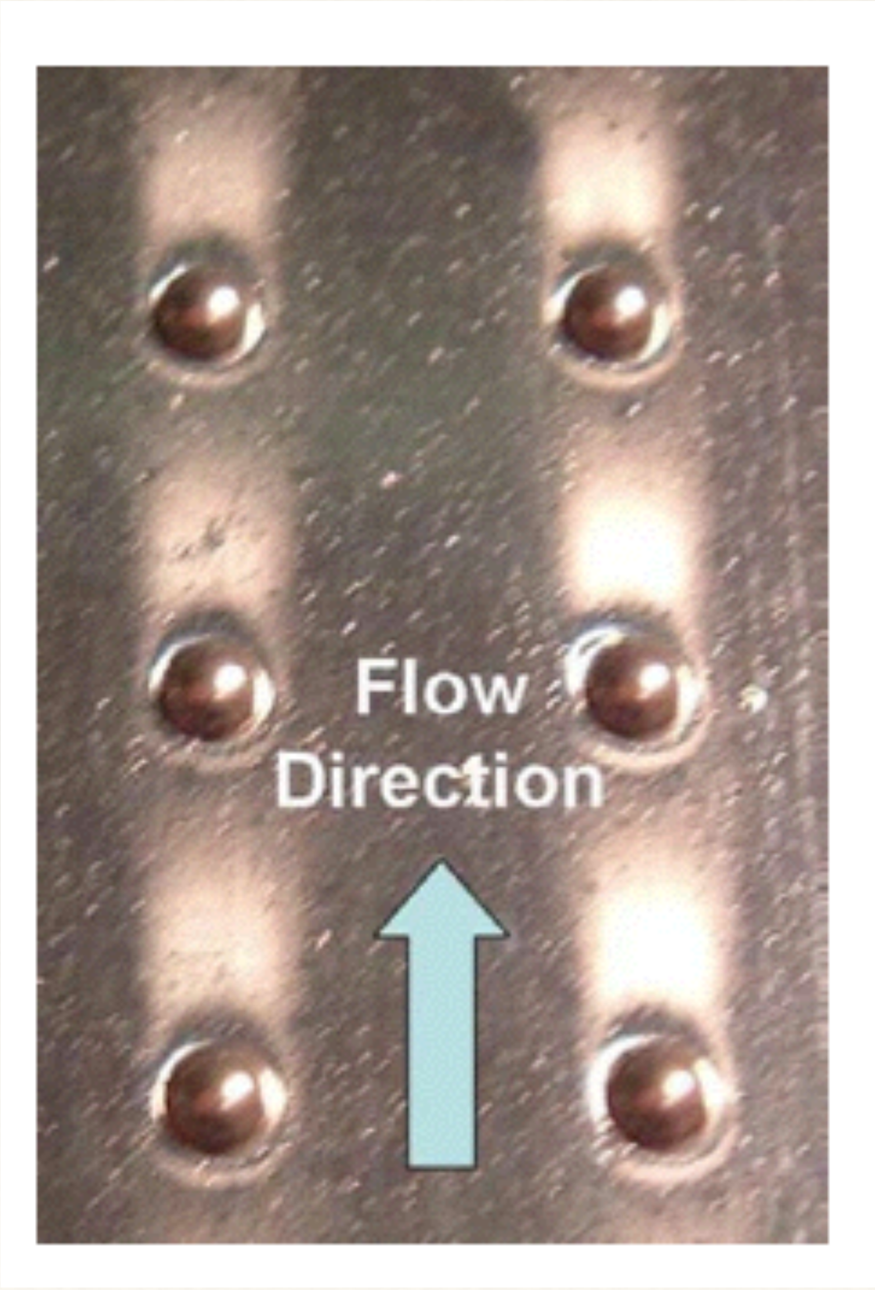
- Smooth wall modeling test (Re_{bulk} = 300,000)



- Reynolds stresses: R_{xy}

Numerical tests

- Rough wall modeling test
  - Validation test: simulations of turbulent flow over rough surface.
  - Half-sphere elements.
  - High Reynolds number flow.

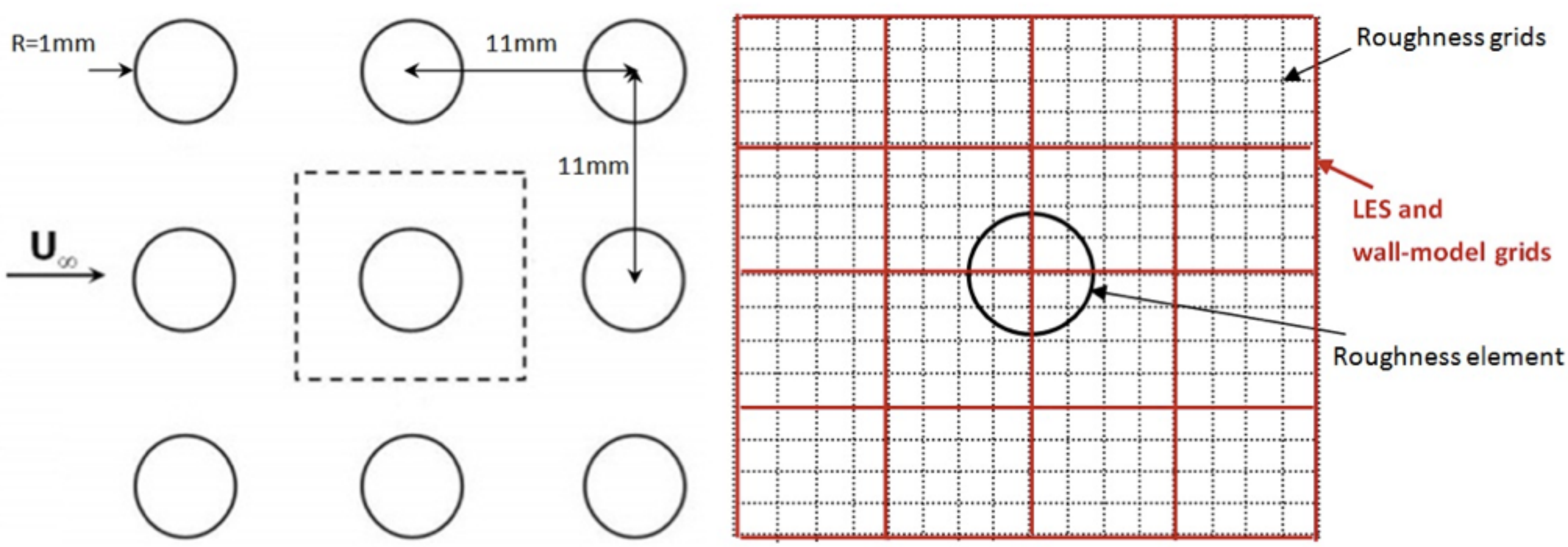


Numerical tests

- Case setup: rough wall modeling test.

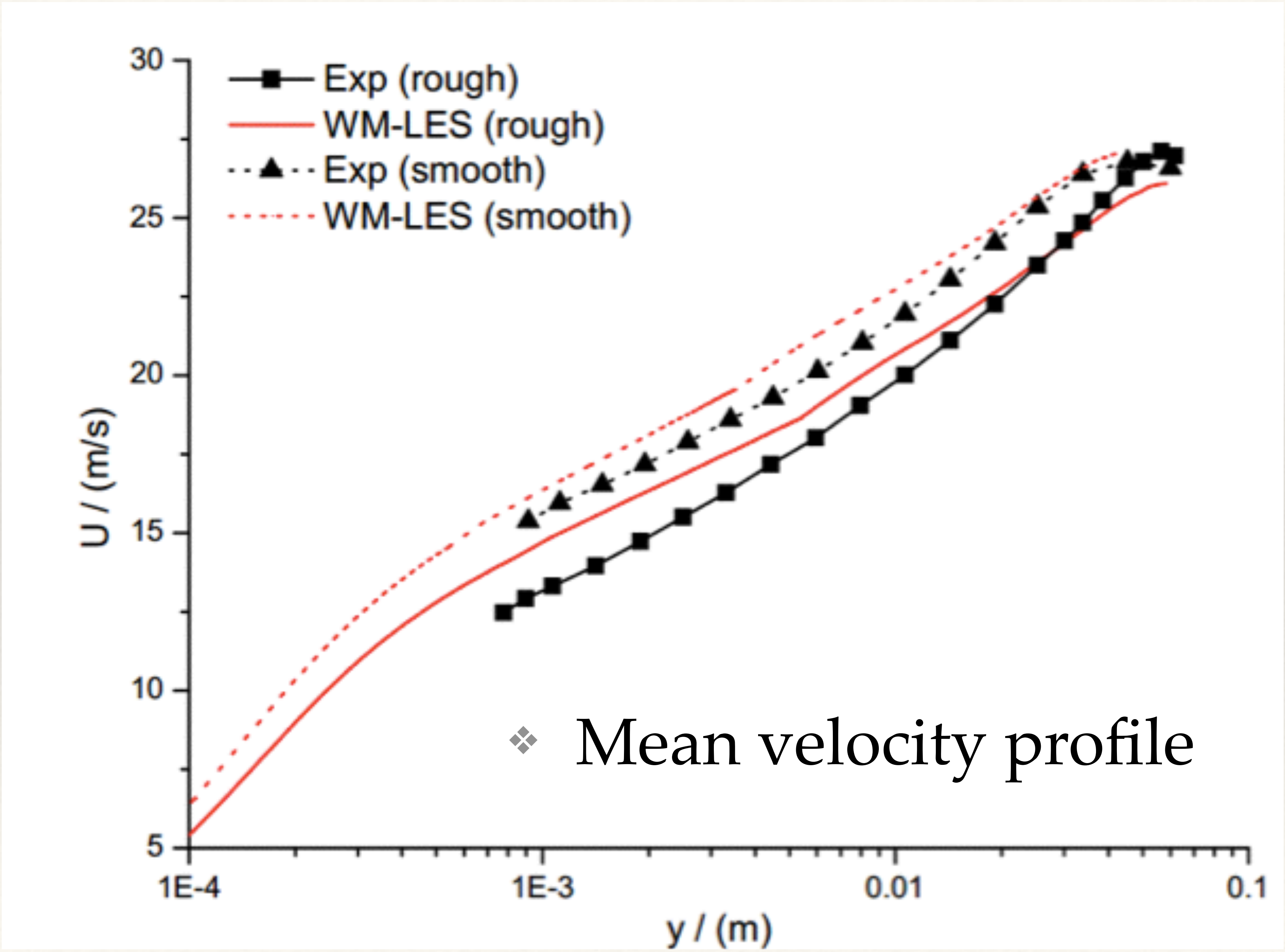
Reynolds number (Re	100,000	domain size	0.22 m × 0.06 m × 0.11 m
average flow velocity	27 m/s	CFD cells	80 × 30 × 40
y+	80	computational cost	400 CPU hours
roughness element diameter	2 mm	distance between elements	11 mm

Numerical tests



Numerical tests

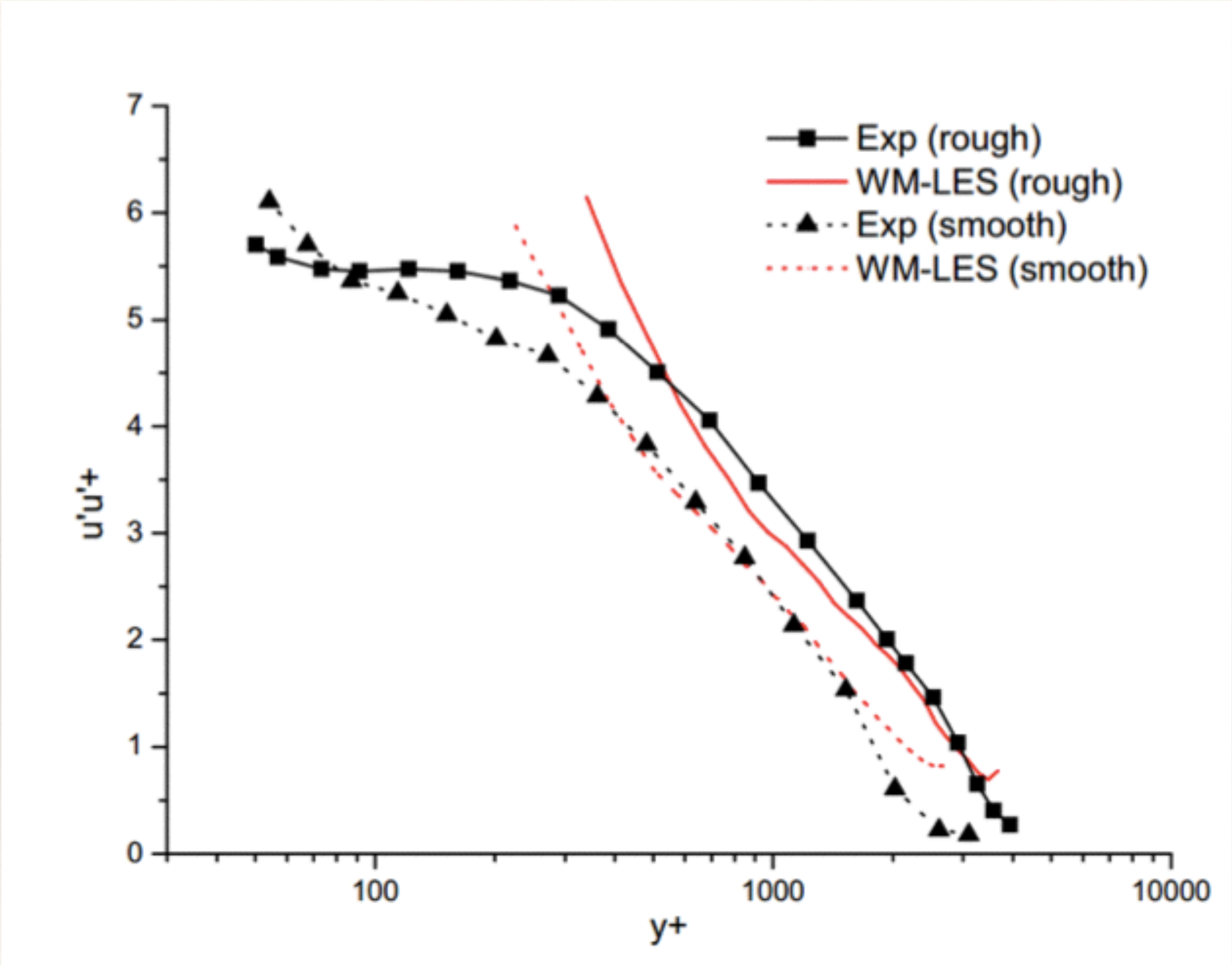
- Rough wall modeling test:



- Mean velocity profile

Numerical tests

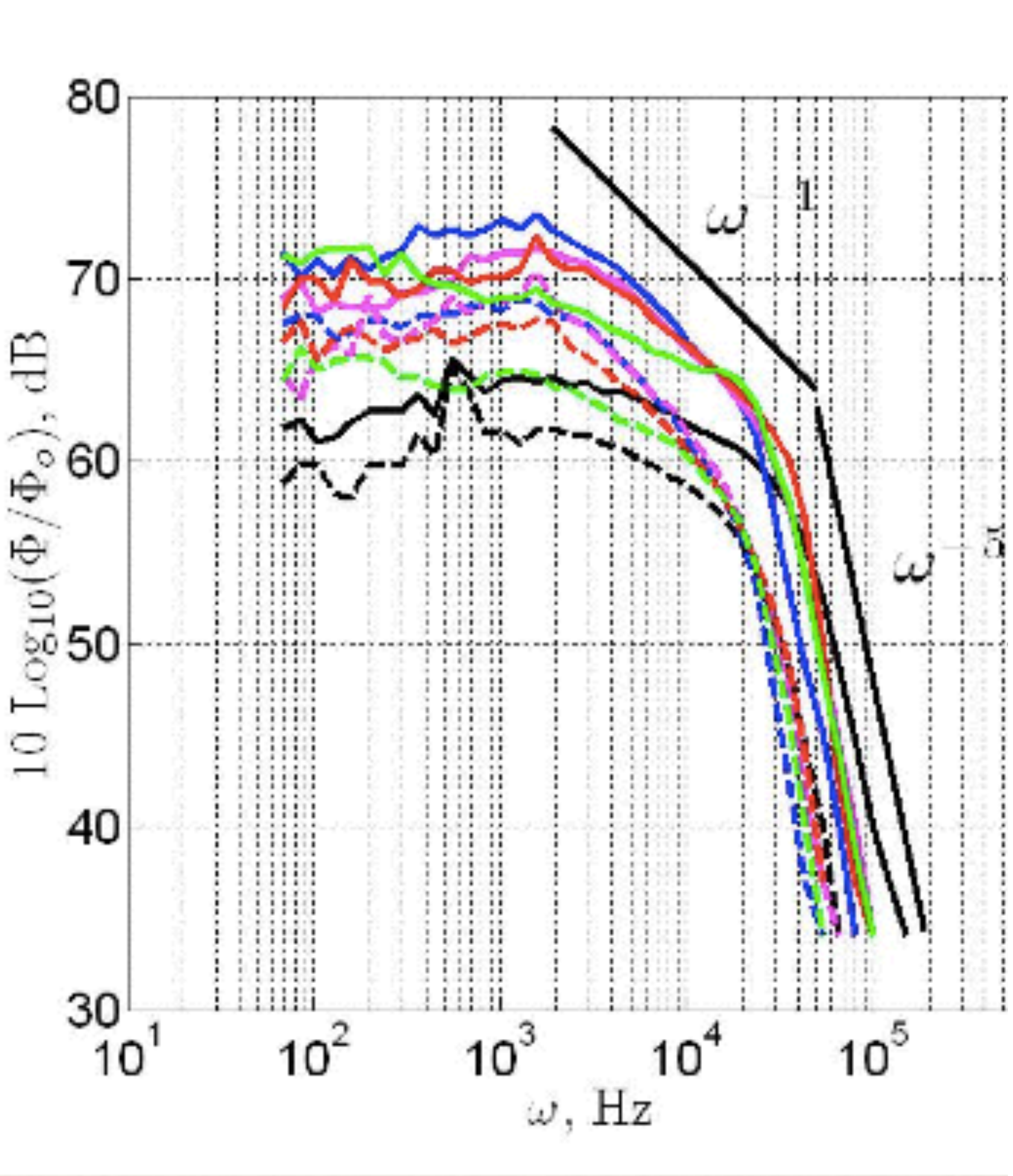
- Rough wall modeling test:

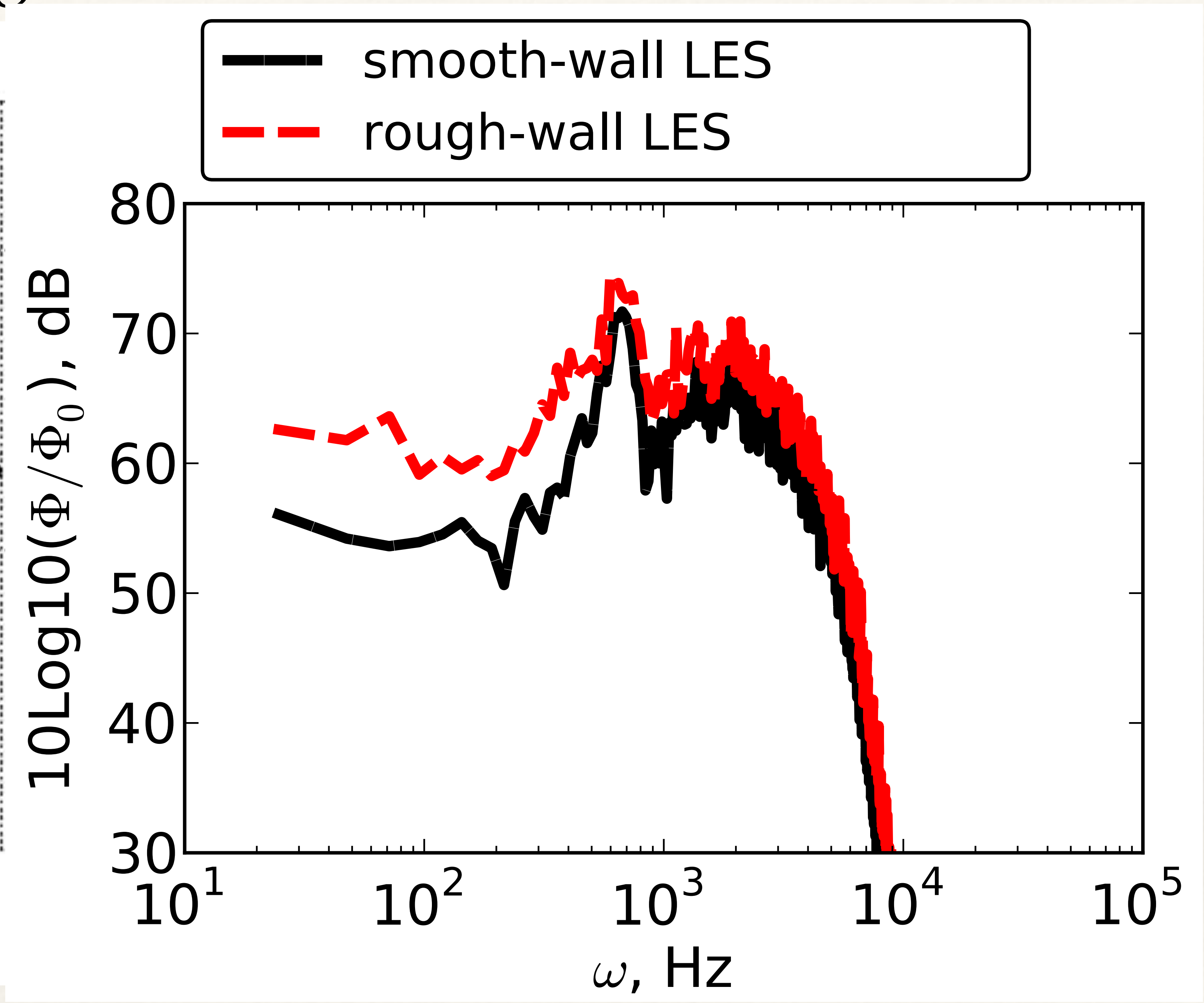


- Reynolds stresses: R_{xy}

Numerical tests

- Rough wall modeling test:





- Power spectral density

Questions?