Numerical uncertainties in the computation of the flow in 2D street canyons

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Aim: Quality assurance and increase of confidence in CFD

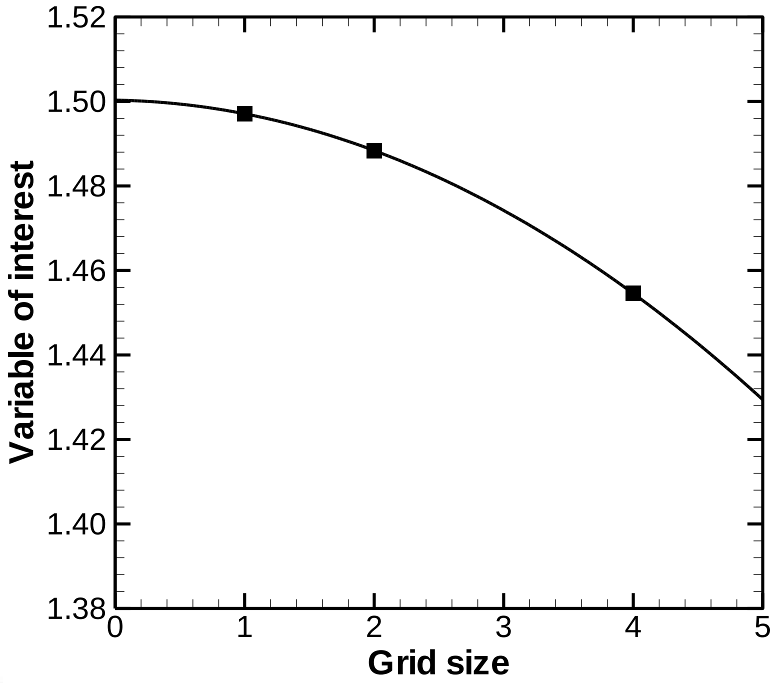
- Verification and validation
- Calculation verification = estimation of numerical errors
- Numerical errors due to:
  - round-off errors
  - incomplete iterative convergence
  - discretisation error
- Exact solution not known

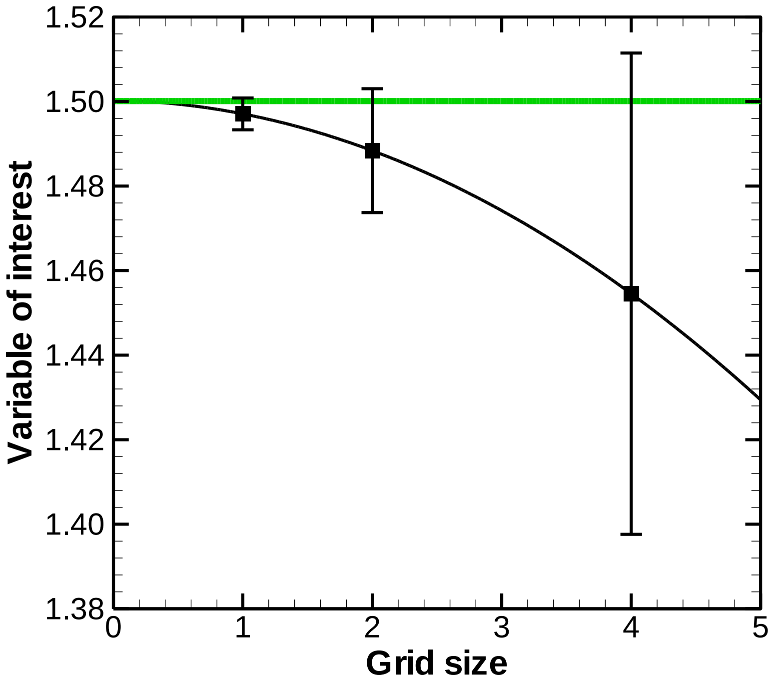
  => numerical uncertainty = numerical error x factor of safety
- Here:
  - double precision
  - iterative convergence down to machine accuracy
  - steady RANS solution

  => only spatial discretisation error

Spatial discretisation uncertainty estimation

- solutions on three sytematically refined grids
- generalised Richardson extrapolation to estimate
  - observed order of the (entire) numerical approximations
  - extrapolated solution for grid size 0
  - multiplication of estimated error with safety factor (here: 1.25)

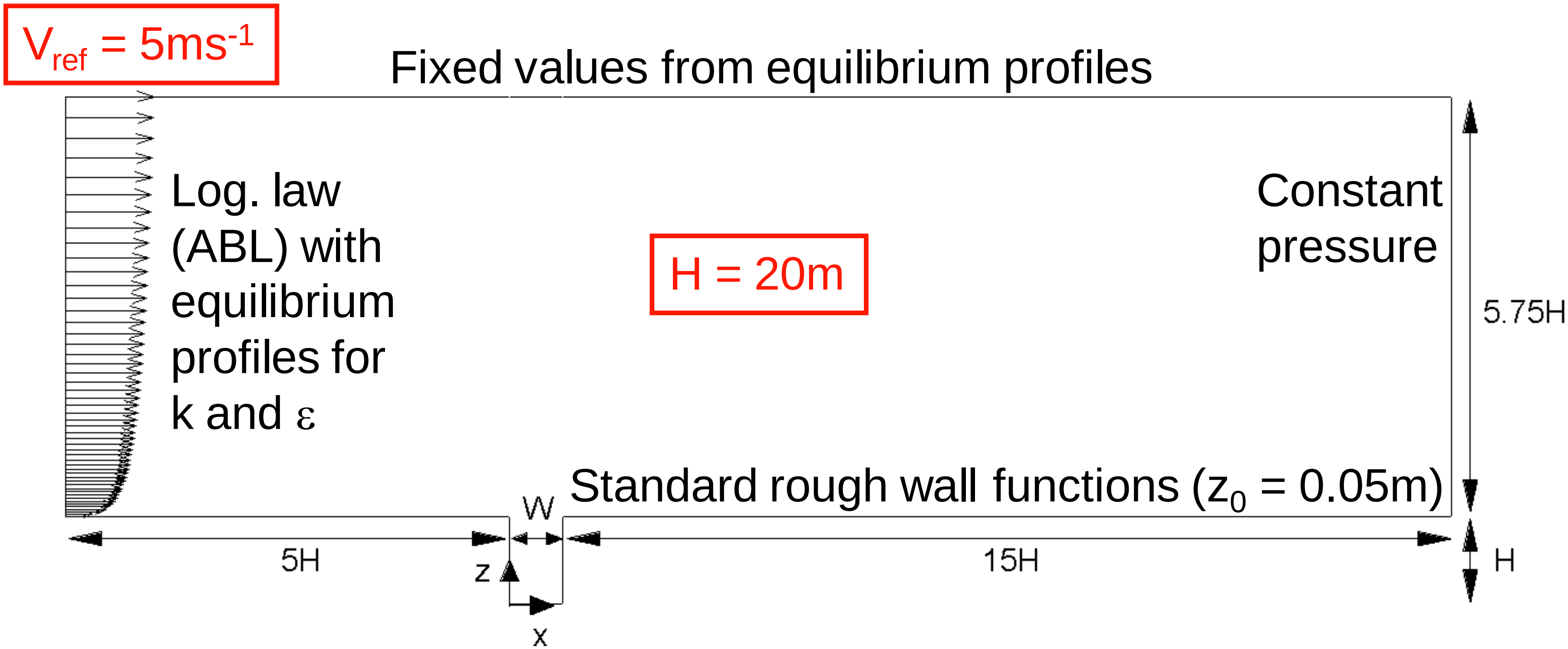




Aim: spatial discretisation uncertainties for flow variables

- test of the recent editorial policy of the ASME Journal of Fluids Engineering for the estimation and reporting on numerical uncertainties
- skimming flow regime
- transition regime from 3 to 2 and from 2 to 1 vortices
- aspect ratios so far: W/H = 0.3, 0.325, 0.35, 0.6, 0.625, 0.65

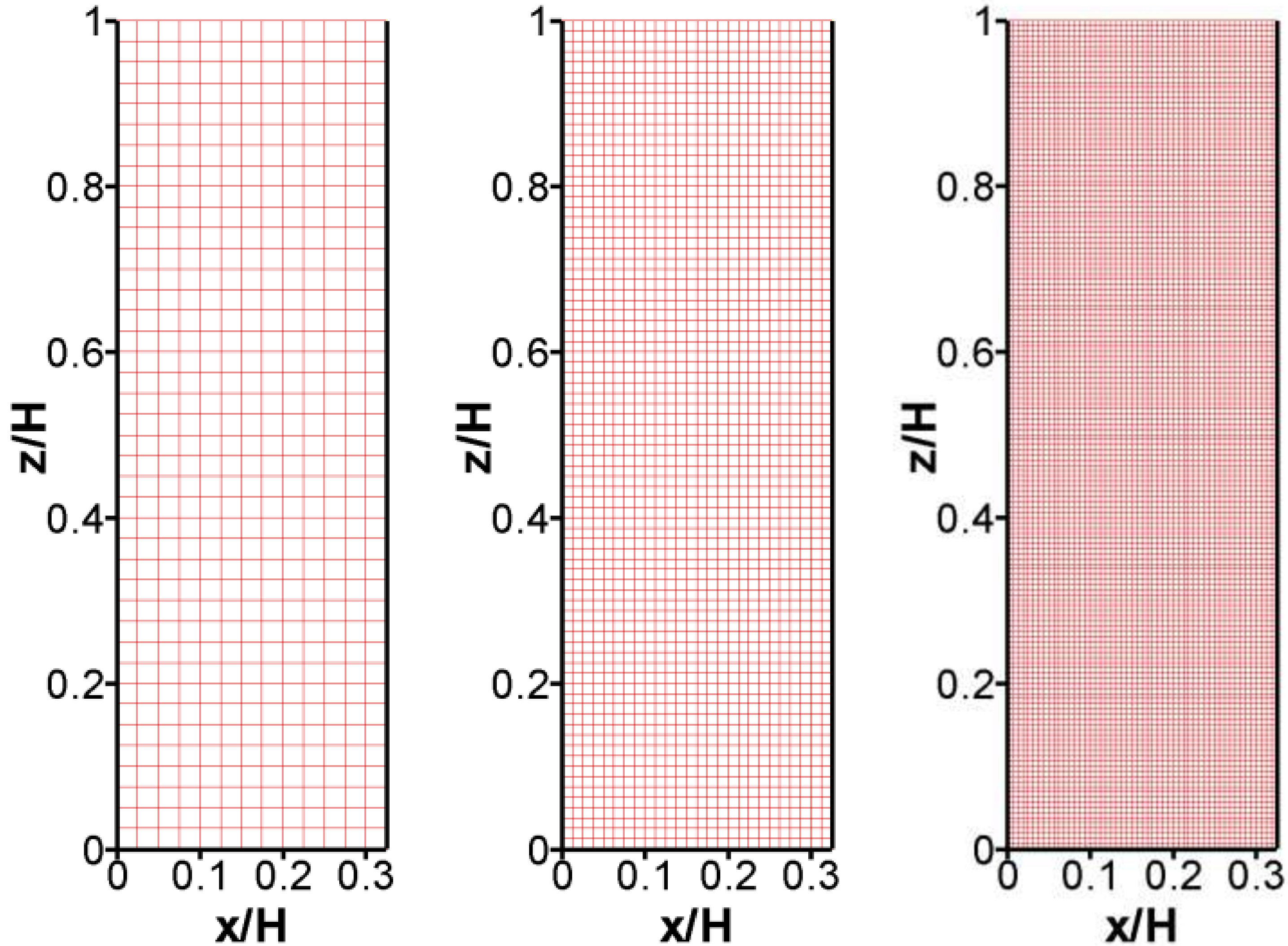
Computational domain and boundary conditions



- Steady RANS with FLUENT V6.3
- Standard k-ε model
- Iterative convergence down to machine accuracy

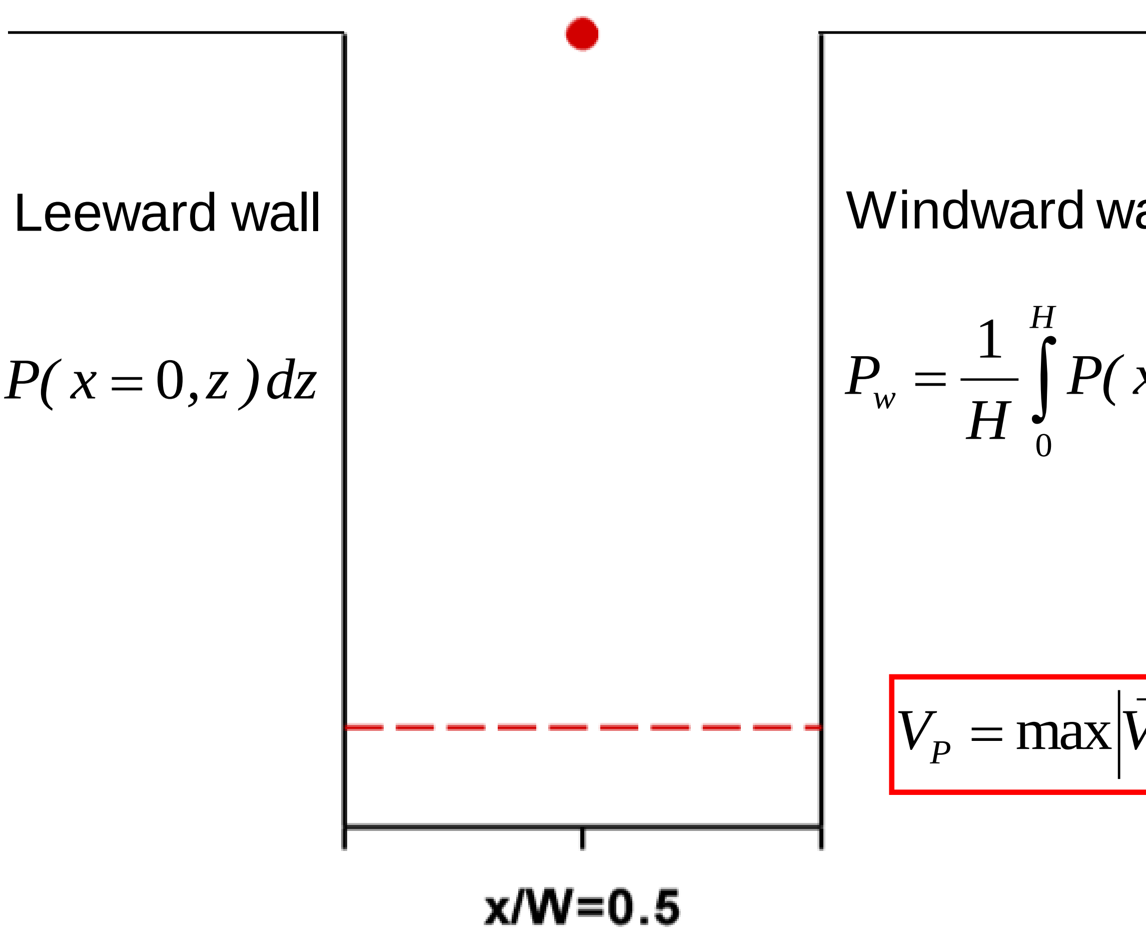
Grids (W/H = 0.325)

Structured grids with doubling of number of cells



Local and integral variables

$$\boxed{V_{HM} = \left|\vec{V}\left(x = W/2, z = H\right)\right|}$$



$$P_l = \frac{1}{H}\int_0^H P(x=0,z)\,dz$$

$$P_w = \frac{1}{H}\int_0^H P(x=W,z)\,dz$$

$$\boxed{V_P = \max\left|\vec{V}\left(x, z = 0.125H\right)\right|}$$

Depending on solution behavior

R = (medium - fine) / (coarse - medium)

I. Monotonic convergence $0 < R < 1$

II. Oscillatory convergence $-1 < R < 0$

III. Monotonic divergence $R > 1$

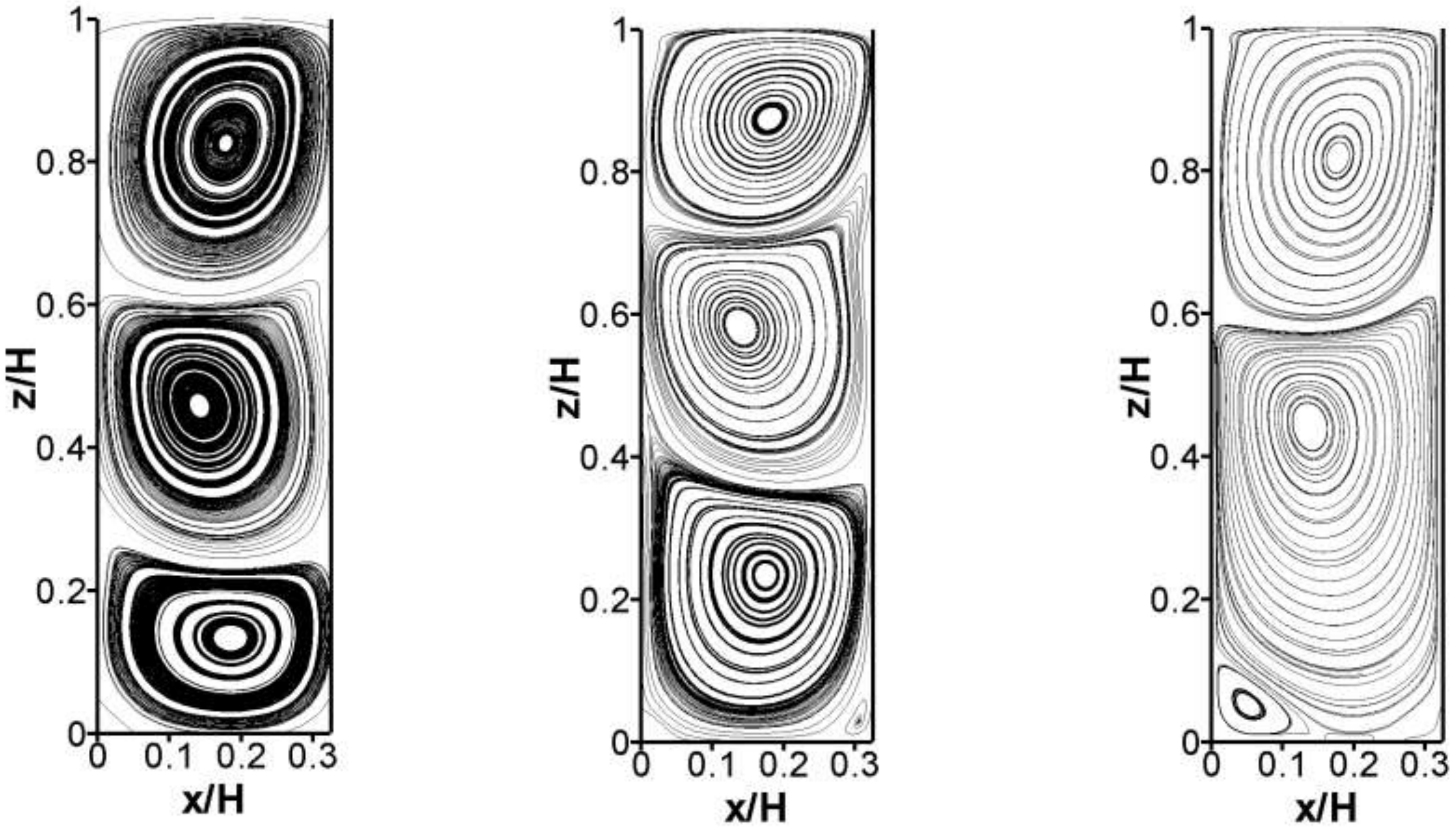
IV. Oscillatory divergence $R < -1$

⇒ **Only 5 of 24 solutions showed monotonic convergence**

⇒ **No simple uncertainty estimation possible!**

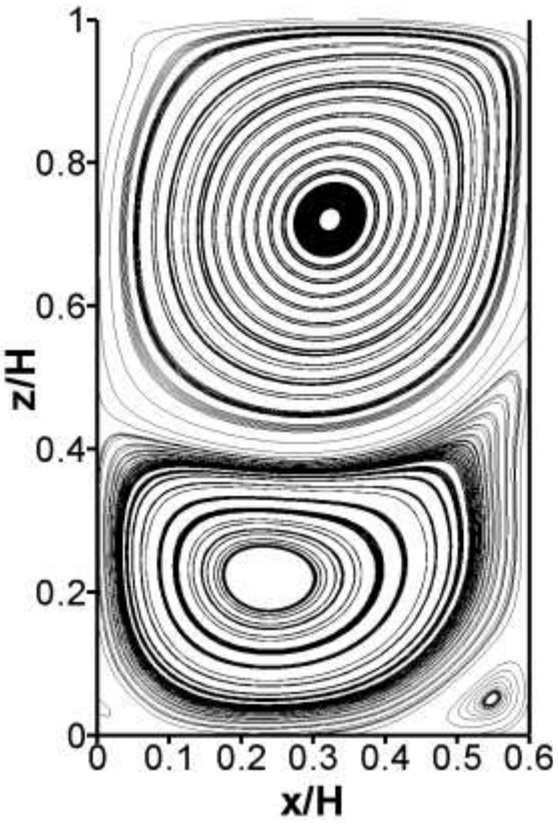
Influence of grid resolution

Coarse grid 2 Medium grid 1 Fine grid 0

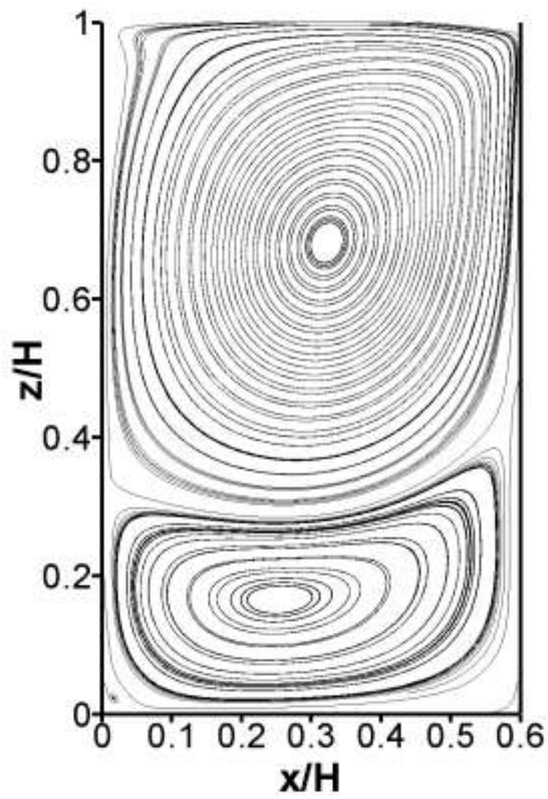


Influence of grid resolution

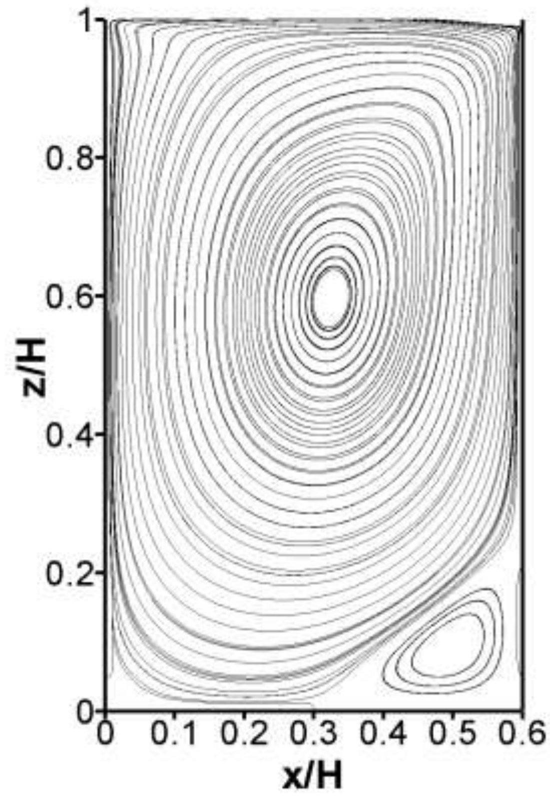
Coarse grid 2



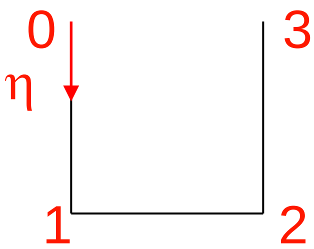
Medium grid 1



Fine grid 0



One problem: wall functions for very fine meshes?

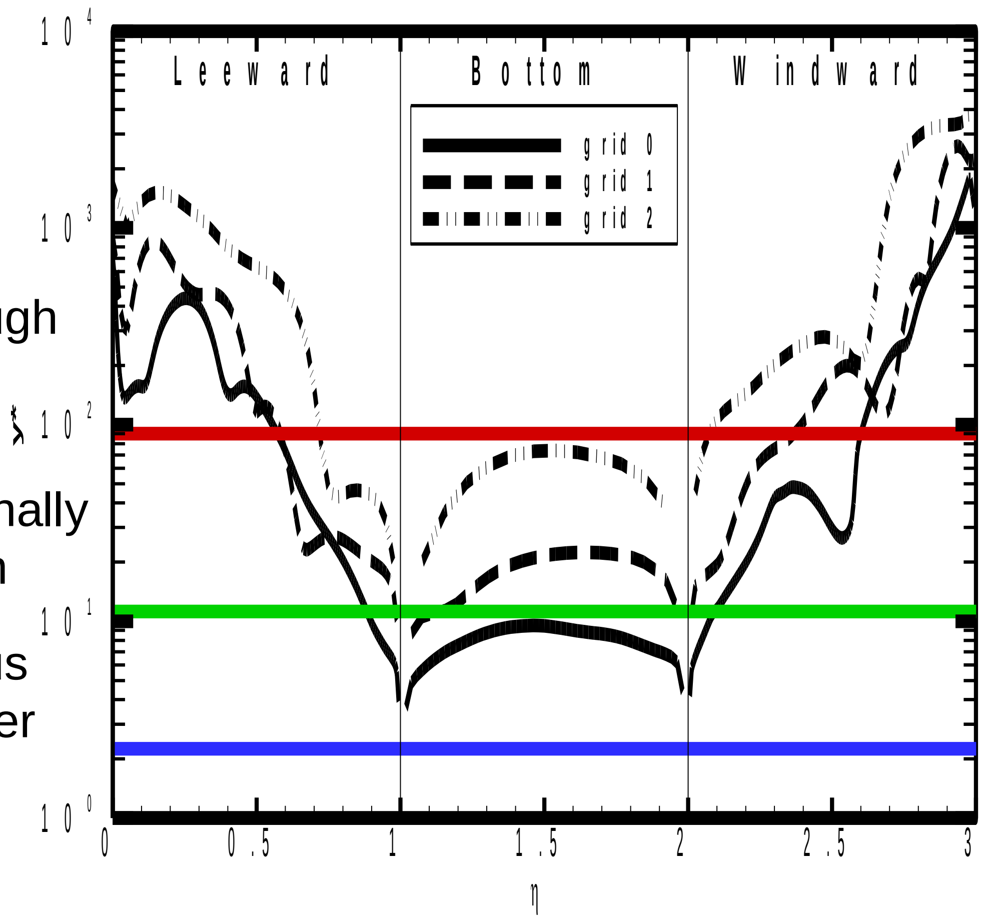


$$y^* = \frac{\rho C_\mu^{1/4} k^{1/2} y}{\mu}$$

Fully rough

Transitionally rough

Viscous sublayer



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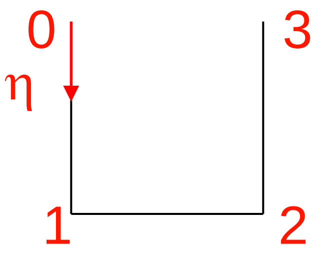

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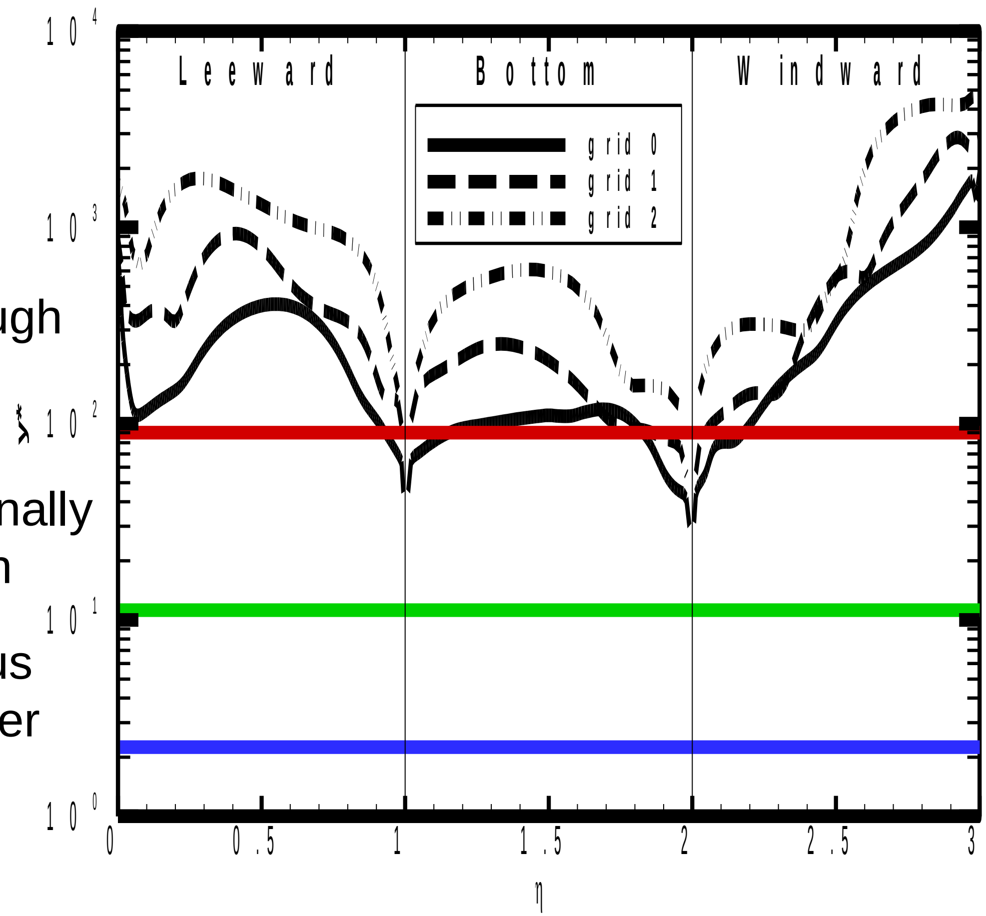
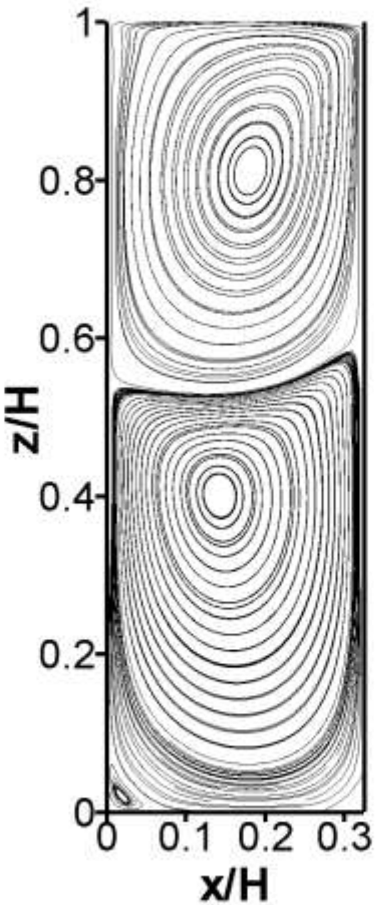


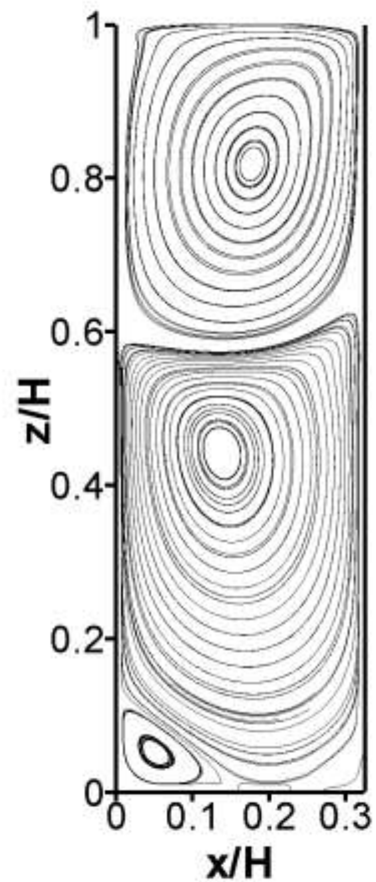
Results (W/H = 0.325)

Influence of approximation for advective/convective terms

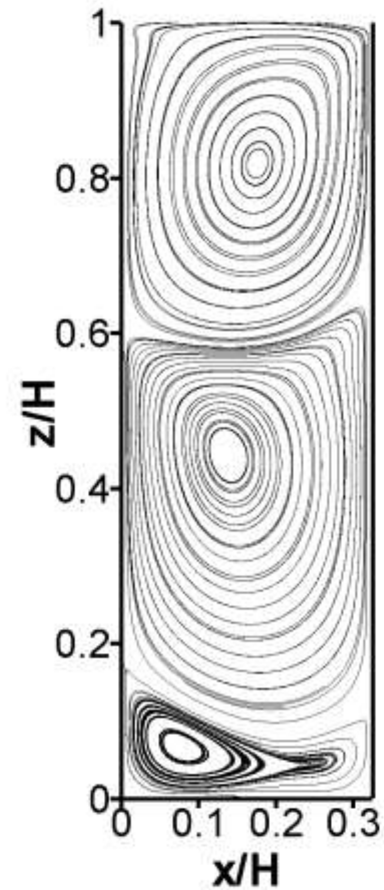
All 1st order upwind



All 2nd order upwind



k and ε 1st, rest 2nd order upwind



Summary / Conclusions

Numerical uncertainty estimation for 2D street canyons

- skimming flow regime with transition between number of vortices
- only spatial discretisation uncertainty (double precision, iterative convergence to machine accuracy)
- hardly monotonic convergence for generalised Richardson extrapolation
- flow field is extremely sensitive to
  - grid resolution
  - approximation of the advective/convective terms
- Standard rough wall functions are problematic with grid refinement