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

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Introduction

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 systematically 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: $W/H = 0.3, 0.325, 0.35, 0.6, 0.625, 0.65$
Physical and numerical parameters

Computational domain and boundary conditions

$V_{\text{ref}} = 5 \text{ms}^{-1}$

Fixed values from equilibrium profiles

- Log. law (ABL) with equilibrium profiles for $k$ and $\varepsilon$
- Standard rough wall functions ($z_0 = 0.05\text{m}$)
- Constant pressure
- $H = 20\text{m}$
- $V_{\text{ref}} = 5\text{ms}^{-1}$

- Steady RANS with FLUENT V6.3
- Standard $k-\varepsilon$ model
- Iterative convergence down to machine accuracy
Structured grids with doubling of number of cells
Analysed variables

Local and integral variables

\[ V_{HM} = |\vec{V}(x = W/2, z = H) | \]

Leeward wall

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

Windward wall

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

\[ V_P = \max |\vec{V}(x, z = 0.125H) | \]
Uncertainty estimation

Depending on solution behavior

\[ R = \frac{\text{medium - fine}}{\text{coarse - medium}} \]

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
One problem: wall functions for very fine meshes?

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