Wall functions for buoyant flows

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Outline

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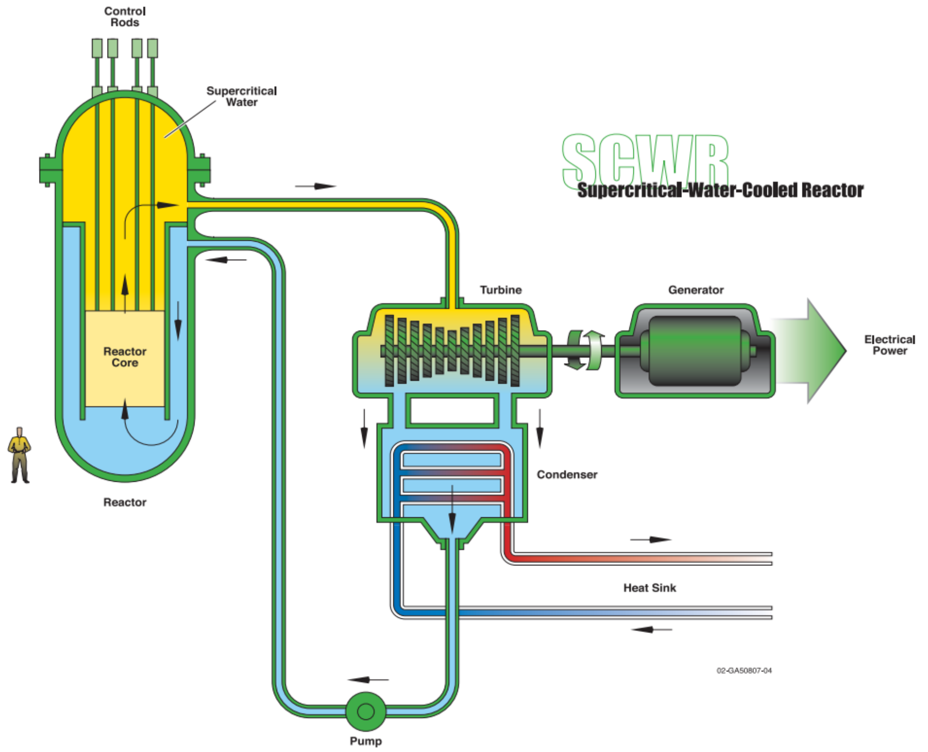
Motivation

- Buoyancy driven flows exist everywhere
- Supercritical water flows, buoyancy close to the wall
- Wall functions in OF cannot handle buoyancy
- Reduction of computational time possible

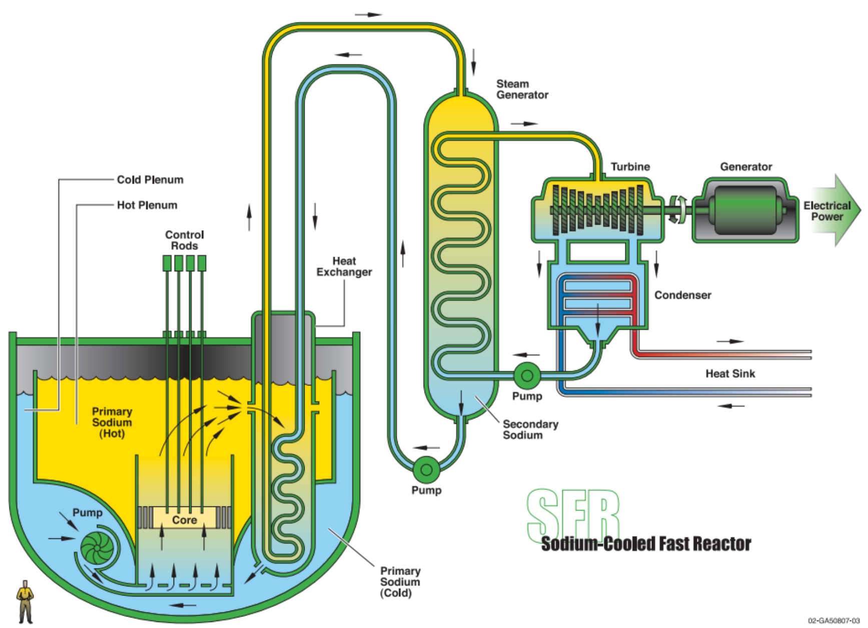
Introduction

- Next generation nuclear power plants use non unity Pr fluids:
  - Supercritical water
  - Liquid metal
  - Gas (CO_2, N_2)
- Buoyancy driven in regular operation (Sodium, LBE/lead)
- Buoyancy driven in accident situations (Gas, LM, SCW)
- Buoyancy effects close to the wall (SCW)

GEN IV Reactors



Supercritical water reactor



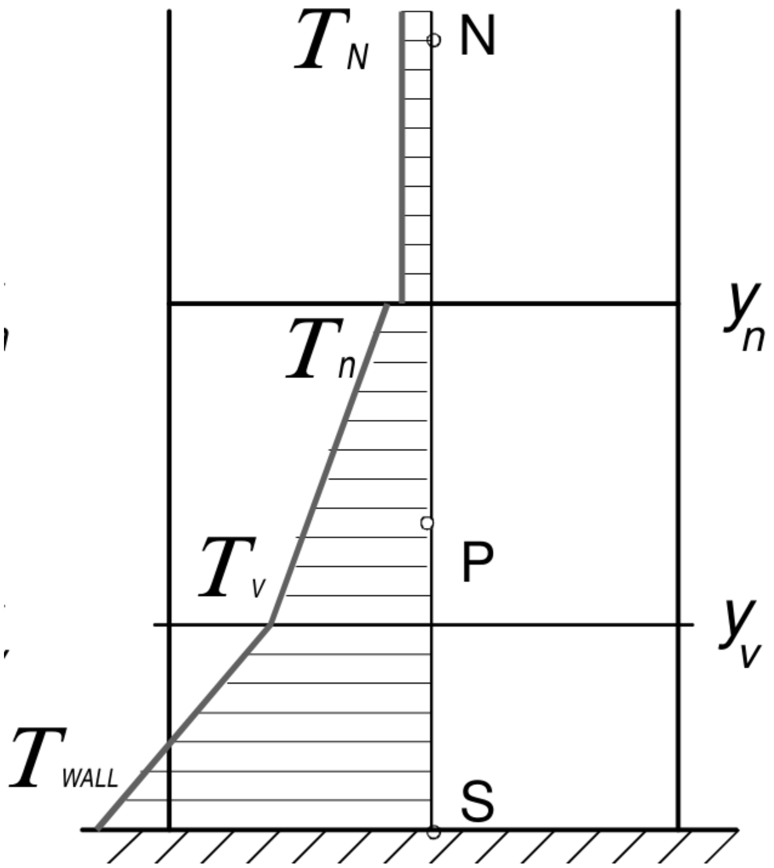
Sodium cooled reactor

Introduction – Water properties

- OF 2.3 does not have water properties accessible
- Use freesteam 2.1 C library
- Use connector from OF real fluid (fork of extend 1.6.x)
- new library which can be loaded in heRhoThermo solvers
  - buoyantPimpleFoam
  - buoyantSimpleFoam
  - chtMultiRegionFoam
  - buoyantBaffleSimpleFoam
- libIAPWSRangeThermo.so available on GitHub
  https://github.com/romansCode/IAPWS-IF97-OF

UMISTA wall function

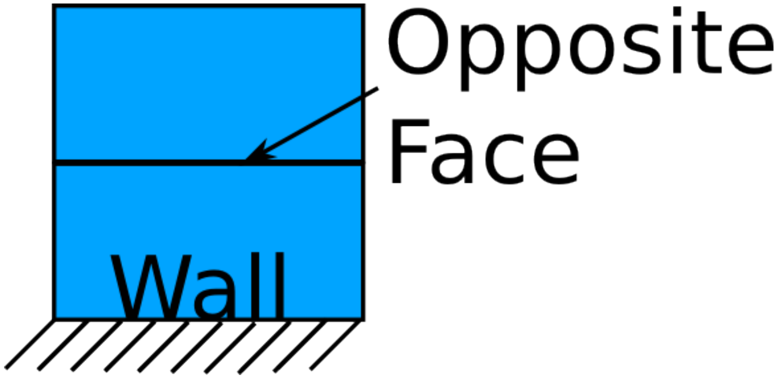
- Analytical integration of the boundary layer equations through viscous and logarithmic layer
- Simplified version, give same results as full temperature variation and is simpler
  - T varies linearly from wall to viscous sublayer edge and from viscous sublayer edge to opposite edge of cell
  - Parabolic description of the molecular viscosity in the viscous sublayer
- Buoyancy terms and near-wall thermal property changes included



Source: Aleksey Gersimov, PhD Thesis, 2003

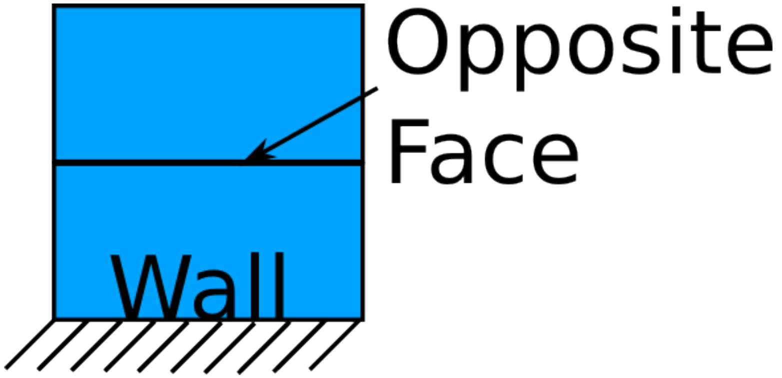
UMISTA wall function

- Original development for 2D staggered mesh with Cartesian coordinates
- OF is 3D, co-located mesh with curvilinear grid and possibility of polyhedral cell
- Restrictions for mesh after implementation
  - Cells must have a cell face opposite the wall



UMISTA wall function ()

- 3 boundary conditions
  - mutkUMISTAWallFunction
    → wall shear stress
  - alphaUMISTAWallFunction
    → wall heat flux
  - epsilonUMISTAWallFunction
    → production and dissipation of k
- 1 momentum source
  - UMISTAExplicitSourceCoeffs
    → handle buoyancy source



UMISTA wall function tuning

Effective Prandtl number

- Usage of effective Pr in first cell
- New equation found based on DNS and DB computations for forced convection

$$Pr_{eff} = \frac{Pr}{0.52 + 0.09Pr^{1.11}}$$

Damping of k-production

- Function based on shear stress ratio
- Can be used for effective Pr as well

$$\lambda_n = \frac{\mu_{wall}\sqrt{\left(\frac{\partial U_i}{\partial y_j}\right)_{wall}\left(\frac{\partial U_i}{\partial y_j}\right)_{wall}}}{\mu_n\sqrt{\left(\frac{\partial U_i}{\partial y_j}\right)_n\left(\frac{\partial U_i}{\partial y_j}\right)_n}}$$

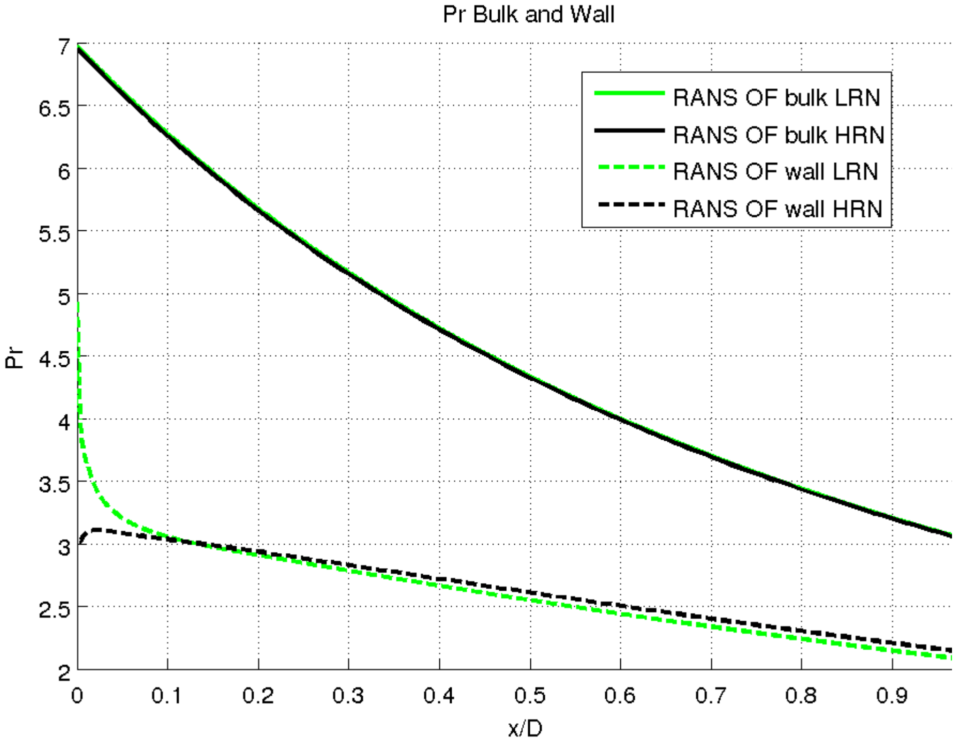
Implementation in OpenFOAM

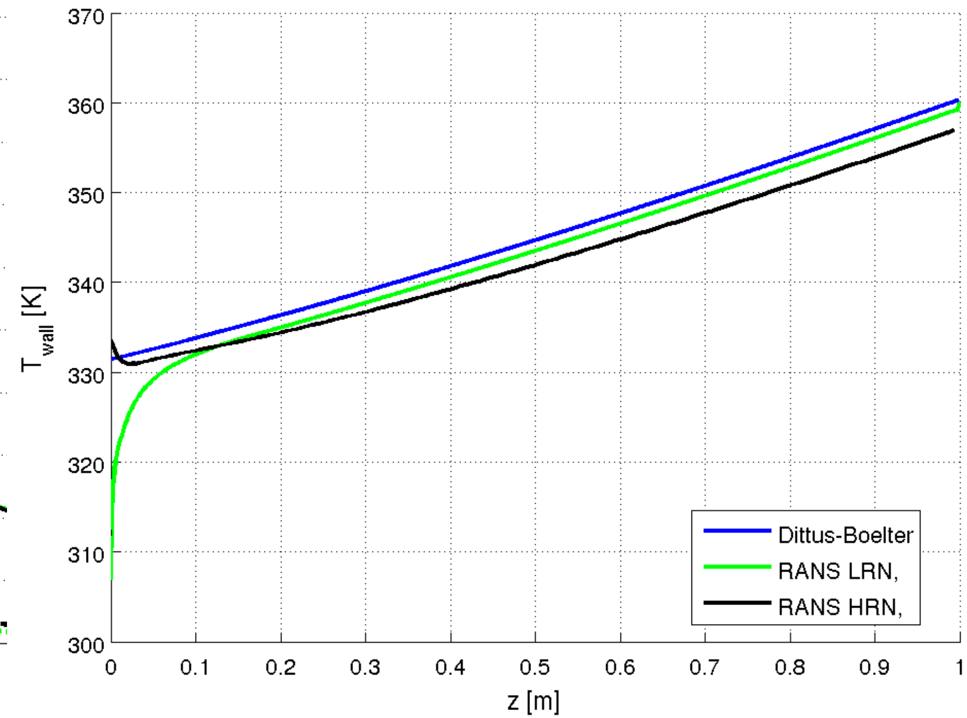
Usage of turbulence properties to insert source terms into the momentum and temperature equation

$$(\mu_{wall} + \mu_{t,wall}) \left(\frac{\partial U}{\partial y} \right)_{wall} = \tau_{wall}$$

$$\mu_{t,wall} = \tau_{wall} \left(\frac{\partial U}{\partial y} \right)_{wall}^{-1} - \mu_{wall} \approx \tau_{wall} \left(\frac{U_P}{y_P} \right)_{wall}^{-1} - \mu_{wall}$$

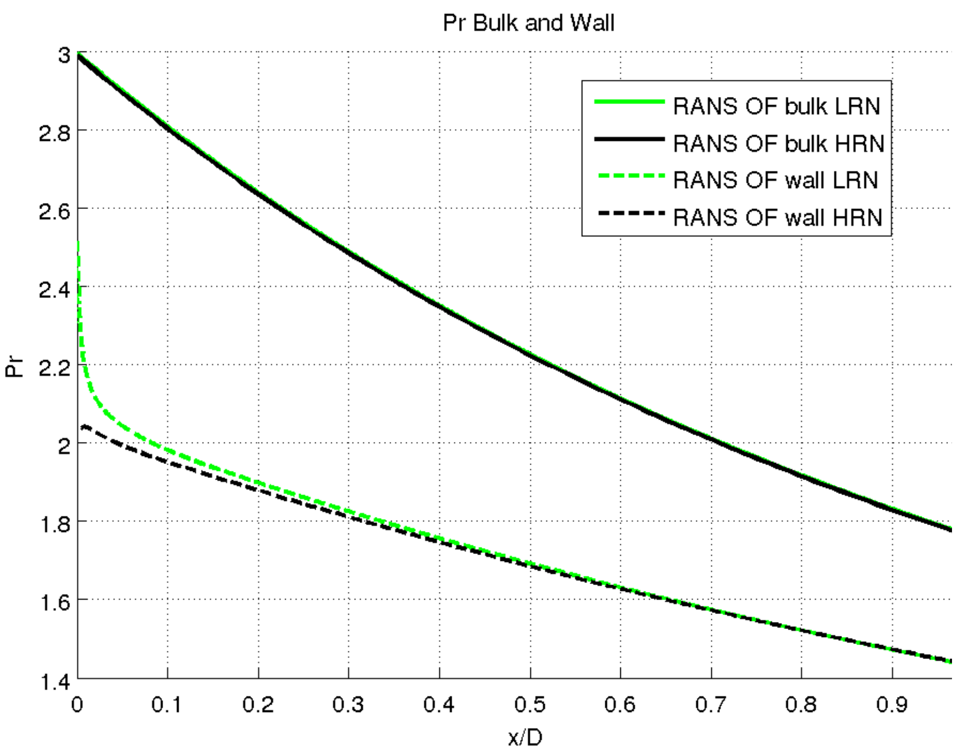
Results DB (forced convection)

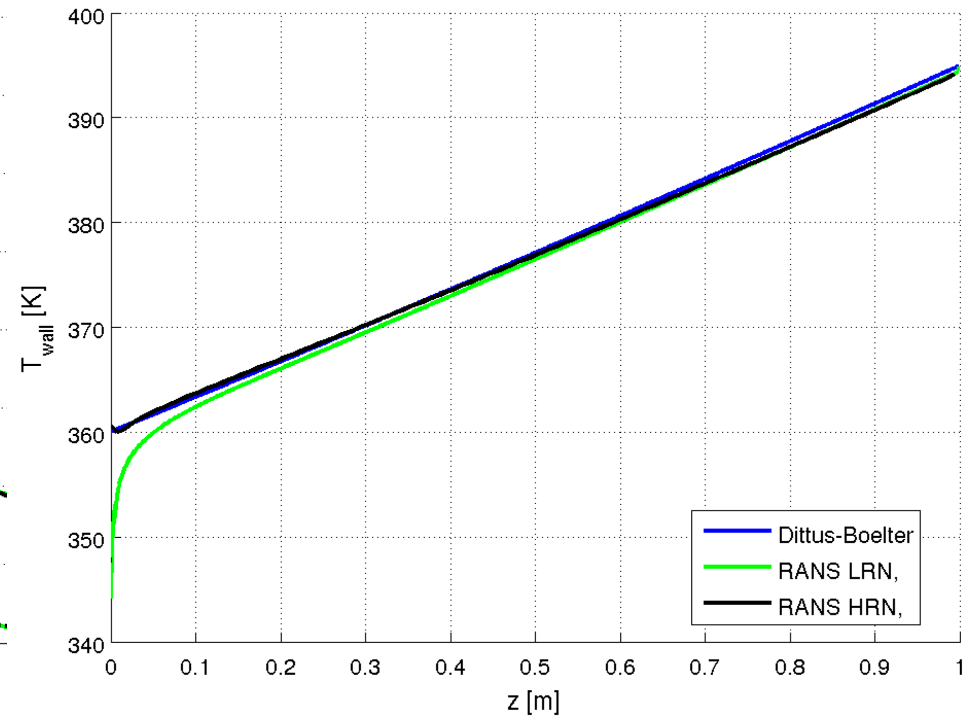




Pr = 7, Re = 5000 to 11000

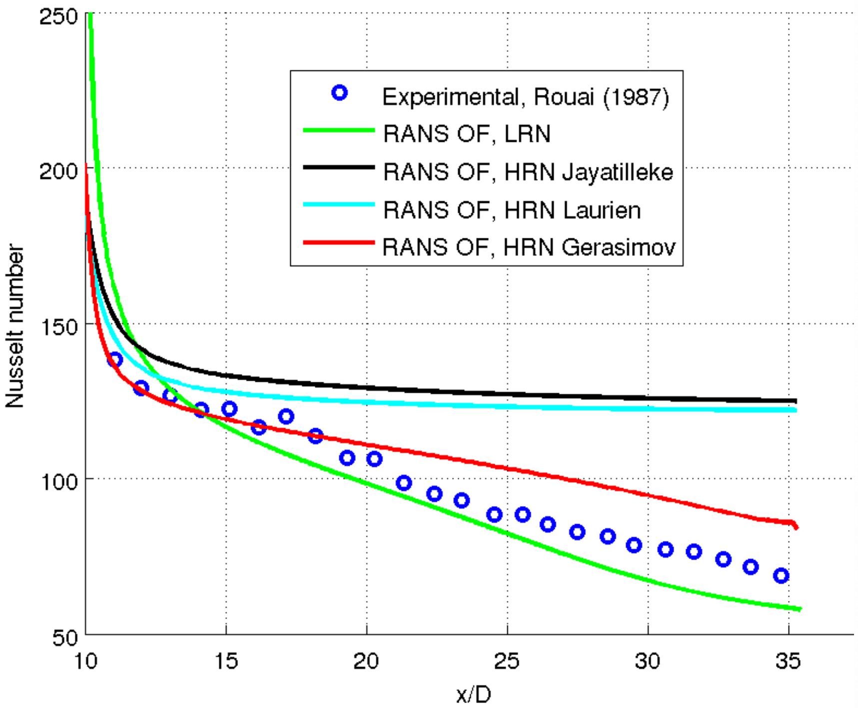
Results DB (forced convection)

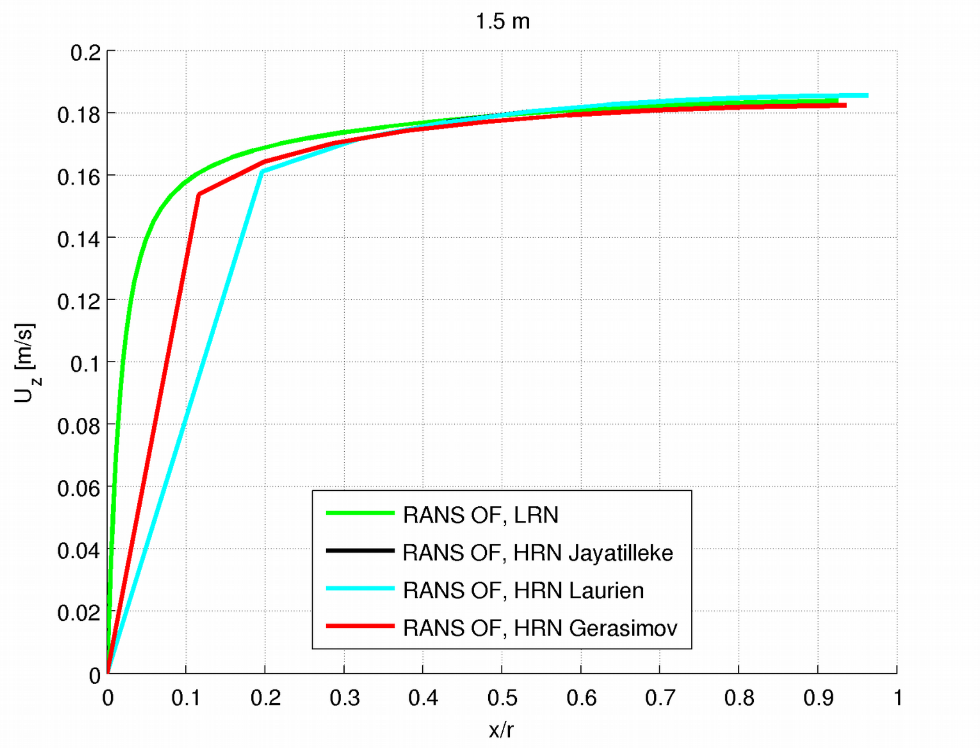




Pr = 3, Re = 10500 to 17400

Results Rouai experiments (mixed convection)





- Mixed convection pipe flow, water, Pr_{in} = 7, Re = 16000, Gr = 4.91e-9
- HRN = 2010 cells, LRN = 35000 cells

Source: Rouai, 1987

Future Work

- Tuning effective Prandtl number:
  - Including for mixed convection
- Tuning of Fepsilon for thinning and thickening of viscous sublayer
- Test against more cases
- Extend to use with supercritical water
- Publish wall function

References

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Thank you for your attention...
Questions?

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