Conjugate heat transfer in turbulent flows inside rough ducts

Umberto Ciri, Kenan Wright & Stefano Leonardi

Department of Mechanical Engineering
The University of Texas at Dallas
Turbulent heat transfer plays a key role in cooling applications (e.g. gas turbine blades)

Roughness elements increase turbulence intensity & promote convective mixing

Han, Dutta & Ekkad (2012)

Cruz-Perez et al. (2012)
Flow configuration

Temperature:
- $T_{\text{cold}}$
- $T_{\text{hot}}$

Dimensions:
- $2h$
- $6.4h$

Ratio:
- $w/k = 1, 3, 7, 15$
- $k/h = 0.05$
Second order central finite difference on staggered Cartesian grid.
Third-order low storage Runge-Kutta.

\[ \frac{\partial U_i}{\partial x_i} = 0 \]

\[ \frac{\partial U_i}{\partial t} + \frac{\partial}{\partial x_j} (U_i U_j) = \frac{\partial P}{\partial x_i} + \Pi \delta_{i1} + \frac{1}{Re} \frac{\partial^2 U_i}{\partial x_j \partial x_j} \]

\[ \frac{\partial T}{\partial t} + \frac{\partial}{\partial x_j} (T U_j) = \frac{1}{RePr} \frac{\partial}{\partial x_j} \left( \tilde{\alpha} \frac{\partial T}{\partial x_j} \right) \]

\[ \tilde{\alpha} = \frac{\alpha_{\text{solid}}}{\alpha_{\text{fluid}}} \]

\[ Re = \frac{U_b h}{n} = 6,900 \]

\[ Pr = 1 \]

Immersed Boundary method for substrate textures.
Performance relative to smooth duct

Results consistent with previous studies on rough walls
Drag increases more than heat transfer
Secondary motion

Streamlines super-imposed to temperature contours

- Corner vortices disrupted into duct-wide rollers
- Secondary motions intensifies and improve mixing

\[ \frac{w}{k} = 7 \]
Conclusions

- Direct numerical simulations of conjugate heat transfer in turbulent duct with roughness elements on the wall

- Roughness elements enhance significantly the heat transfer, although pressure drop increases more

- Classic secondary motion in the duct cross-section is disrupted into duct wide streamwise vortices → more effective mixing → larger heat transfer

Thank you!