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Conjugate heat transfer in turbulent flows inside rough ducts

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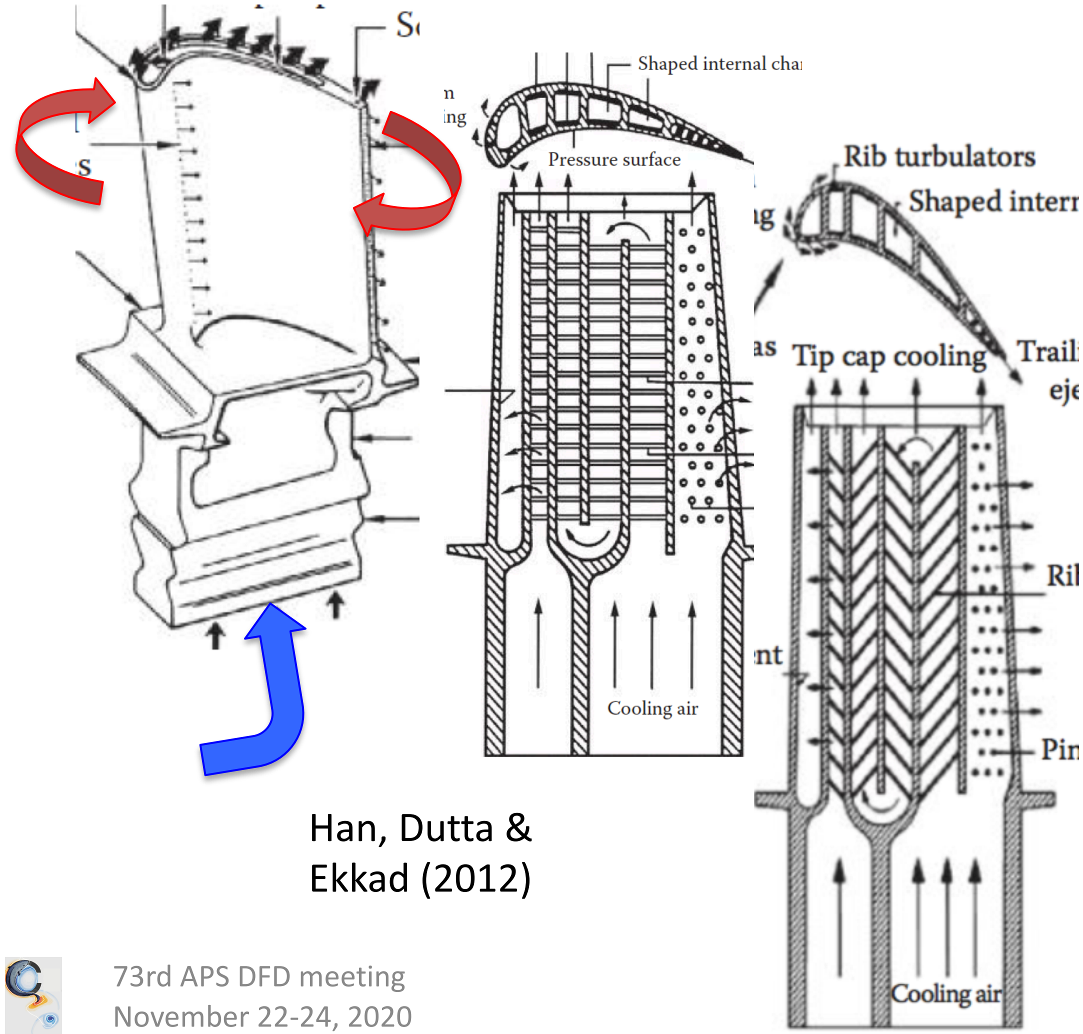
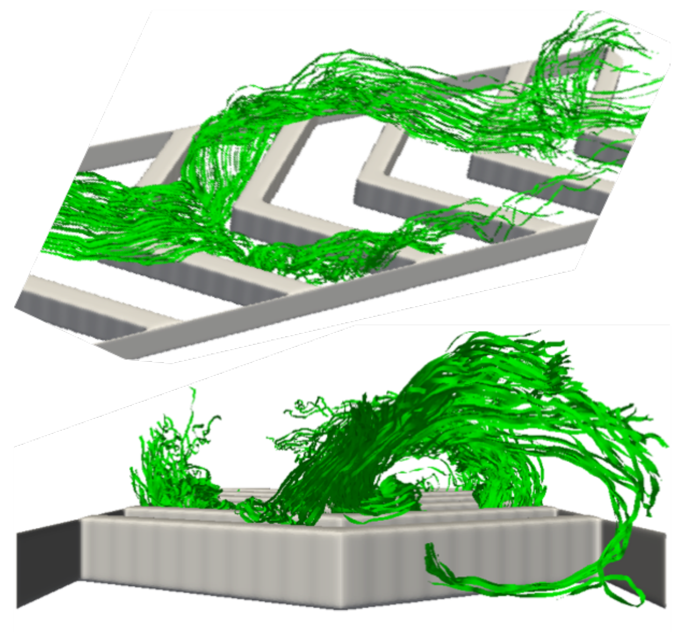
Introduction

Turbulent heat transfer plays a key role in cooling applications (e.g. gas turbine blades)



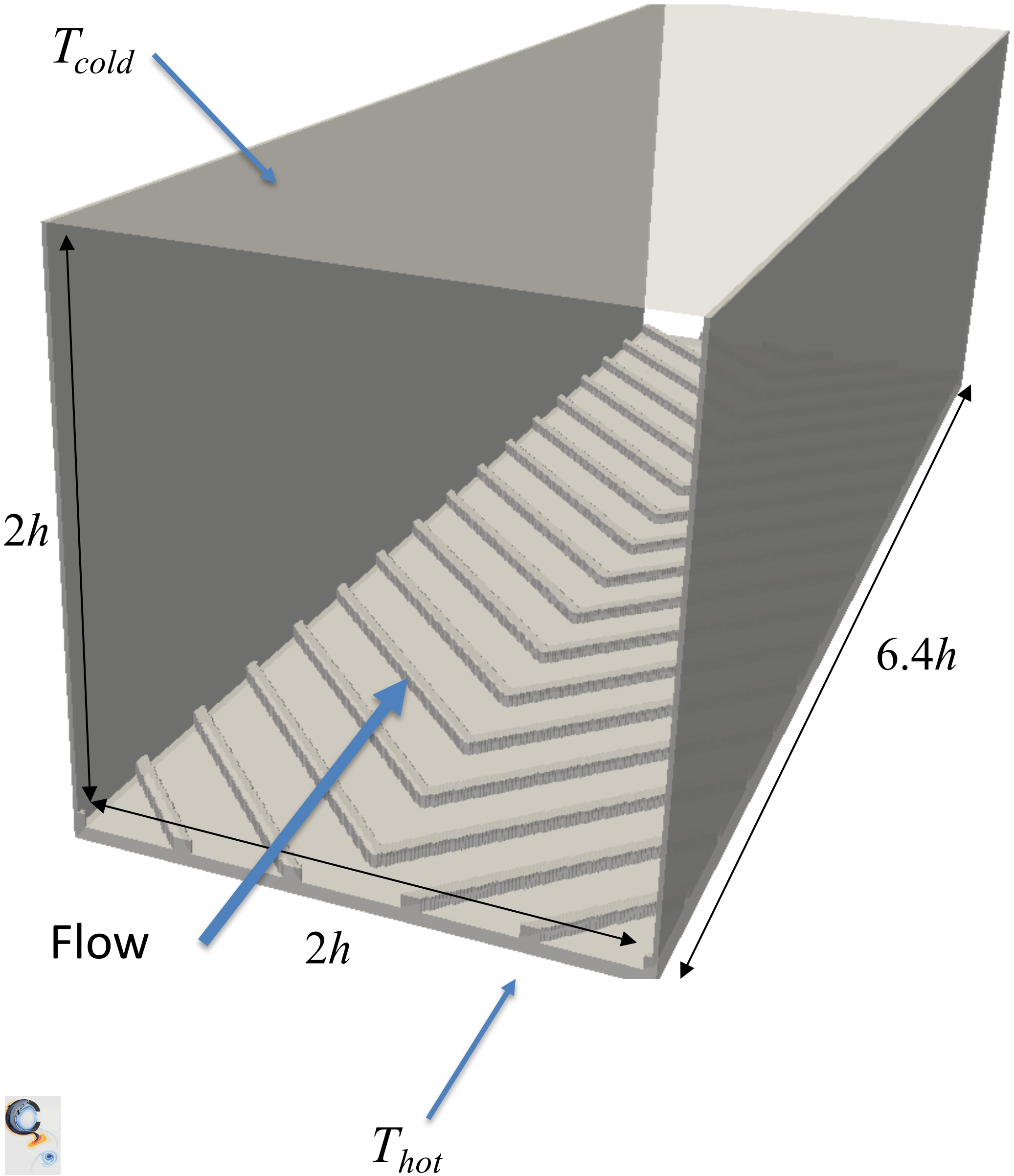
Han, Dutta & Ekkad (2012)

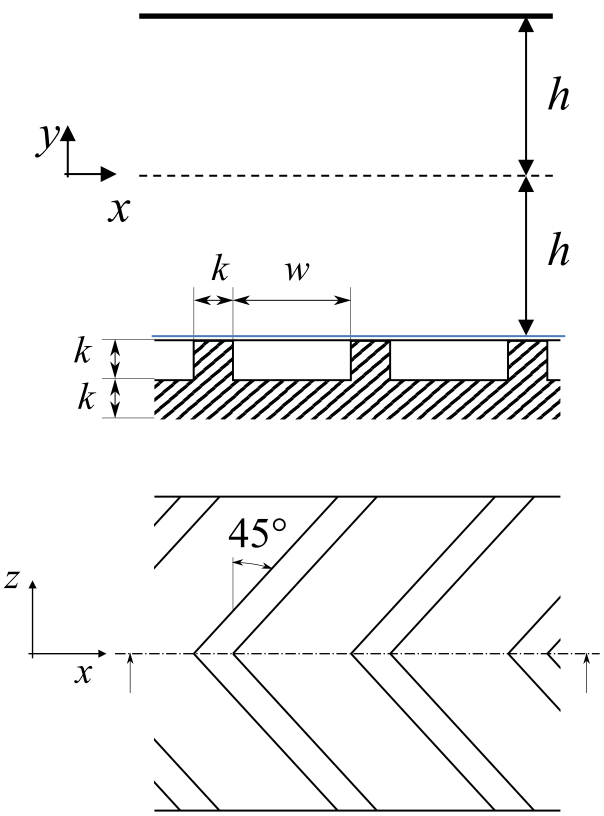
Roughness elements increase turbulence intensity & promote convective mixing



Cruz-Perez et al. (2012) *Proc. ASME Heat Transf.*

Flow configuration





$w/k = 1, 3, 7, 15$

$k/h = 0.05$

Numerical methodology

$$\frac{\partial U_i}{\partial x_i} = 0$$

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

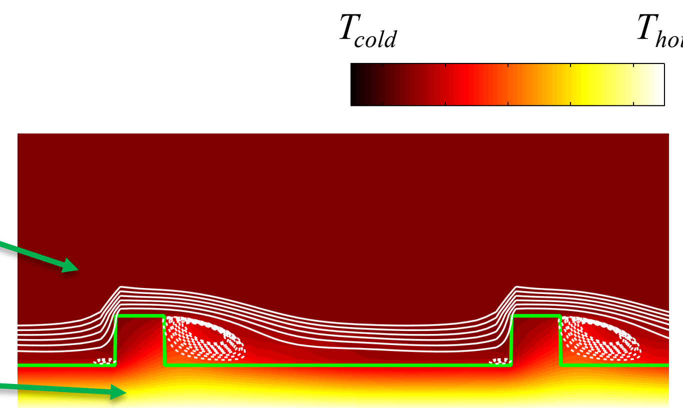
$$\frac{\partial T}{\partial t} + \frac{\partial}{\partial x_j}\left(T U_j\right) = \frac{1}{RePr}\frac{\partial}{\partial x_j}\left(\tilde{\alpha}\frac{\partial T}{\partial x_j}\right)$$

$Re = U_b h/n = 6{,}900$

$Pr = 1$

$\tilde{\alpha} = 1$

$\tilde{\alpha} = \frac{\alpha_{solid}}{\alpha_{fluid}}$



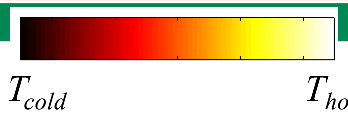
Second order central finite difference on staggered Cartesian grid.

Third-order low storage Runge-Kutta.

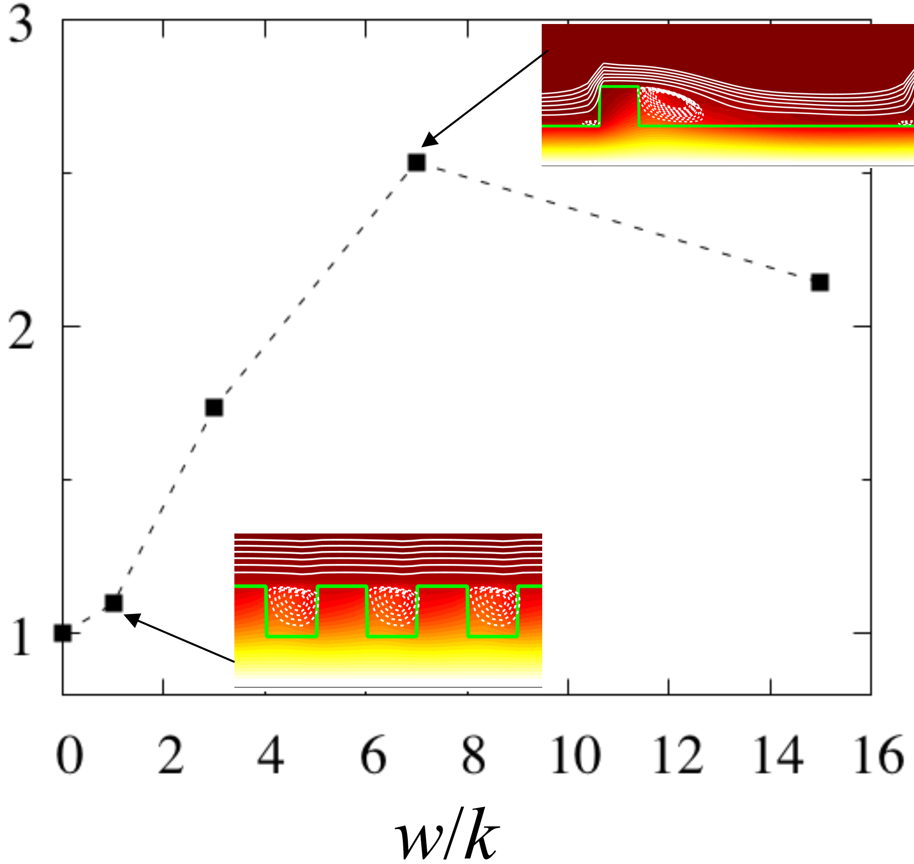
Immersed Boundary method for substrate textures.

Performance – drag & heat transfer

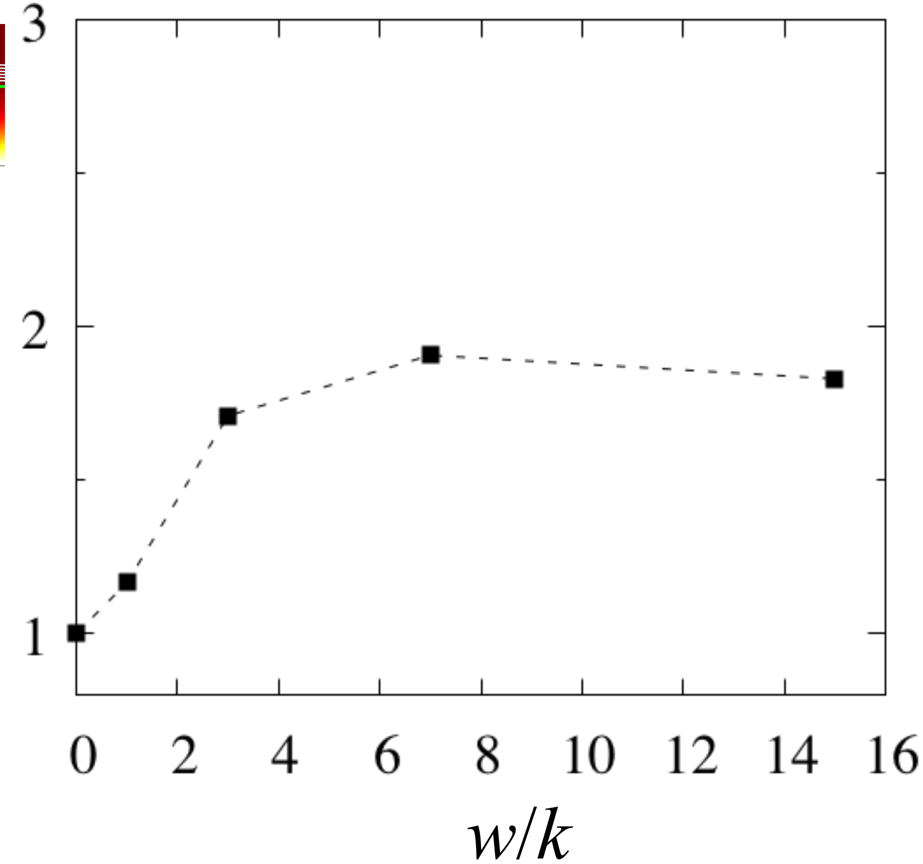
Performance relative to smooth duct



Pressure drop $\Delta p / \Delta p_0$



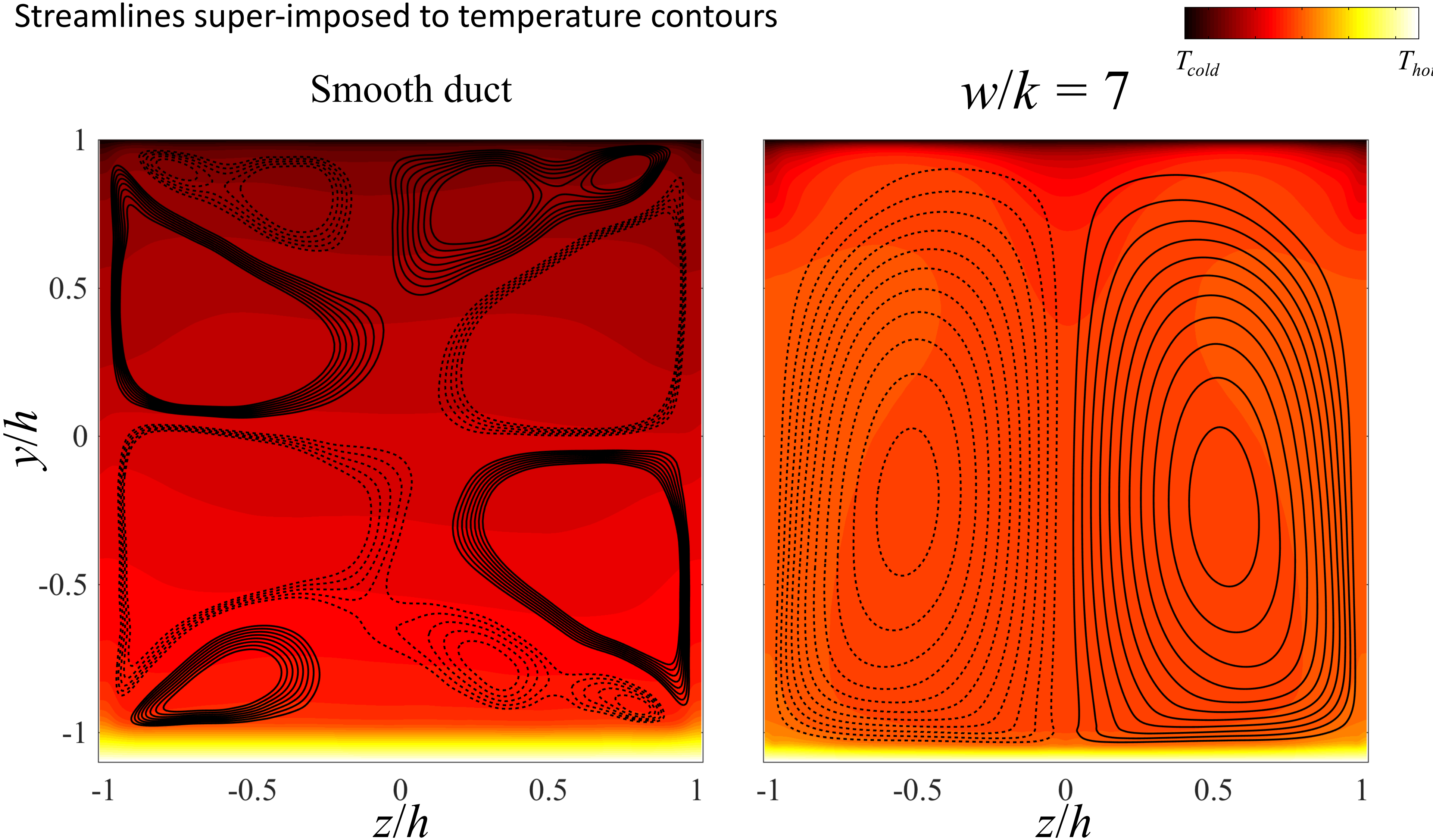
Surface heat flux q/q_0



- 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

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!