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H13-031

Pollutant Transfer Coefficient in Street Canyons of Different Aspect Ratios

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Parallel Session 1

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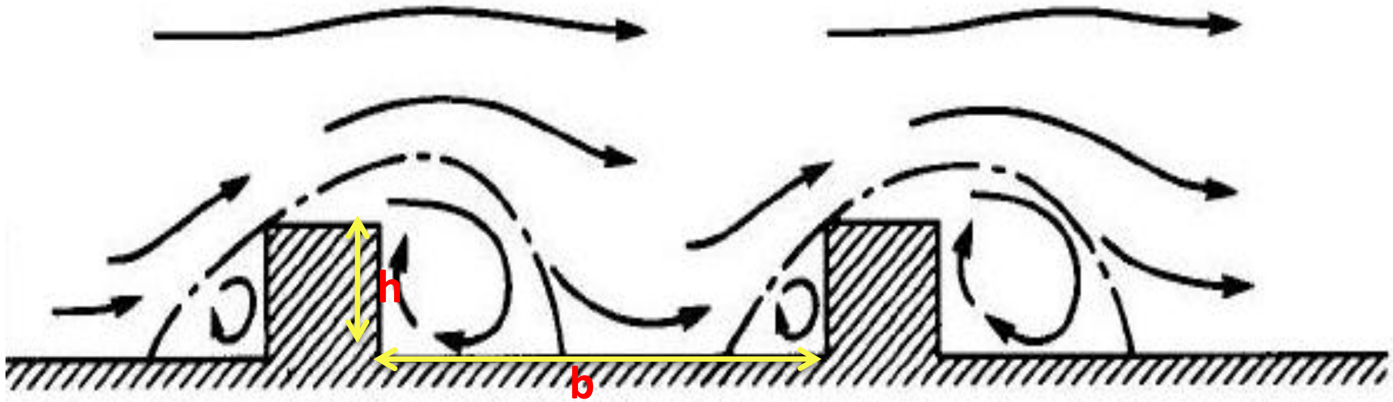
Rundown

- Introduction
- Objectives
- Local transfer coefficient (LTC) equation
- Model description
- Model validation
- CFD results
- Conclusion

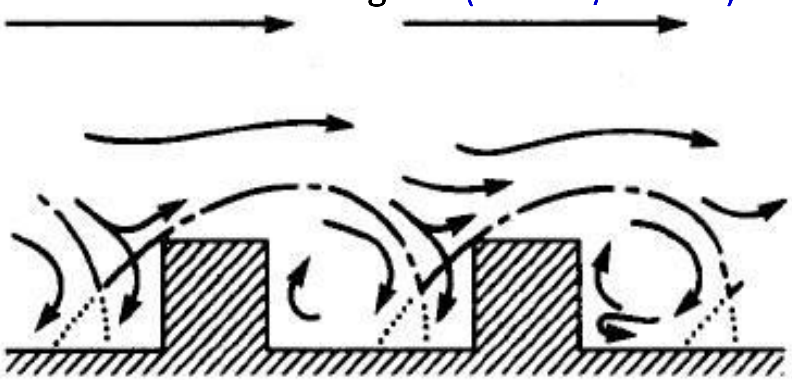
Introduction

- Flow regimes (Oke, 1988)

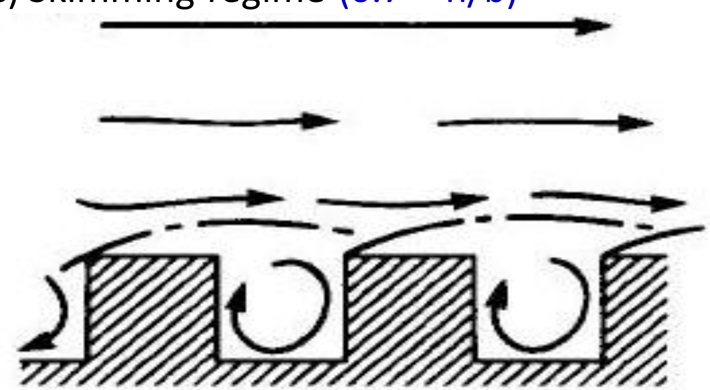
a) Isolated roughness regime (h/b < 0.3)



b) Wake interference regime (0.3 < h/b < 0.7)

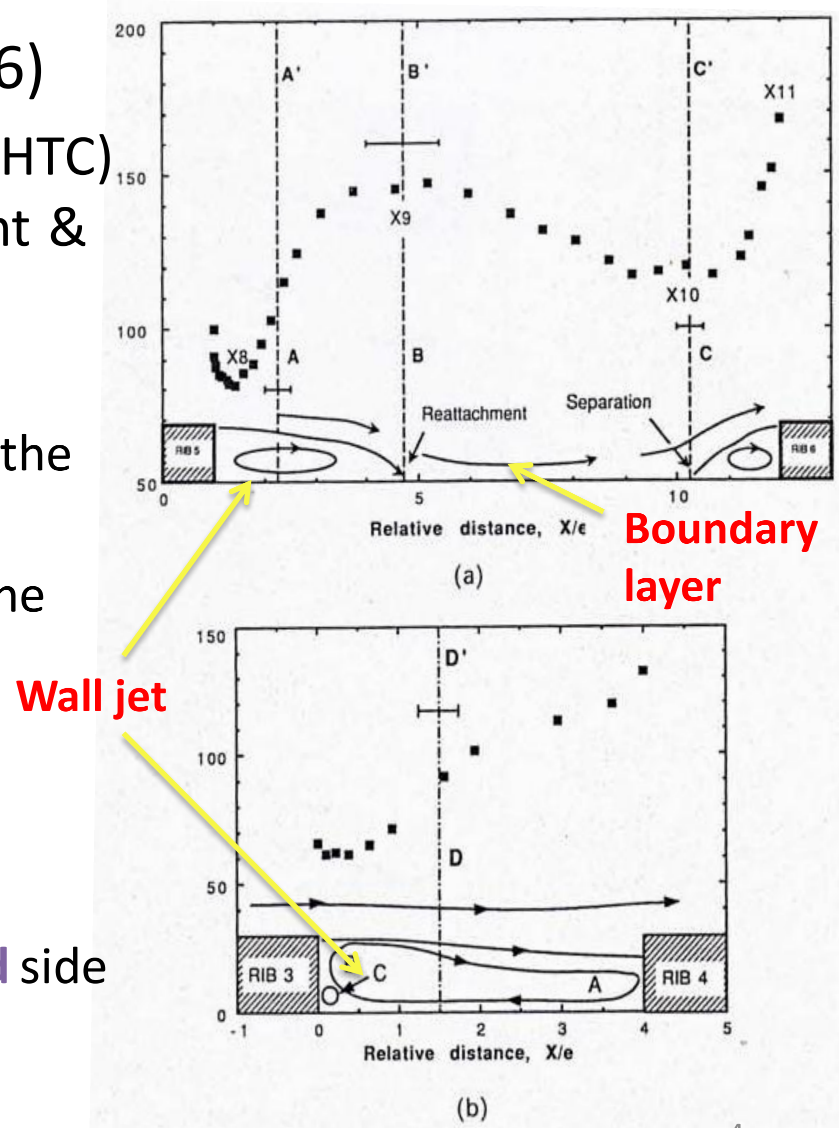


c) Skimming regime (0.7 < h/b)



Introduction

- Aliaga et al. (1994) & Hishida (1996)
  - The local heat transfer coefficient (LHTC) is closely related to the reattachment & separation of the flow
    - ➢ *Isolated Roughness Regime*
      - The **maximum** LHTC coincides with the **reattachment** point
      - The **minimum** LHTC overlaps with the **separation** point
    - ➢ *Wake Interference Regime*
      - **Monotonic increment** of LHTC
      - **No peak or trough**
      - **Maximum** locates on the **windward** side



Objectives

- Examine the pollutant dispersion behavior along the street inside the street canyon
- Elucidate the mechanism of pollutant removal through the roof level of the street canyon

as a function of the building-height-to-street-width (aspect) ratio (AR) h/b

Analogue to Pollutant Transfer

- Convection-Diffusion Equation

$$\frac{\partial \theta}{\partial t} + u_j \frac{\partial \theta}{\partial x_j} = \alpha \frac{\partial^2 \theta}{\partial x_j^2}$$

  - θ is the temperature
  - α is the thermal diffusivity

- Mass Transport Equation

$$\frac{\partial \phi}{\partial t} + u_j \frac{\partial \phi}{\partial x_j} = \kappa \frac{\partial^2 \phi}{\partial x_j^2}$$

  - ϕ is the mass/pollutant concentration
  - κ is the mass diffusivity

Computational Fluid Dynamics (CFD)

- Large-eddy simulation (LES)
  - Two-length-scale modeling
    - Large eddies & small eddies
  - One-equation subgrid-scale (SGS) model
  - Open-source CFD code OpenFOAM 1.6
- *k*-*ε* turbulence model
  - One-length-scale modeling
  - The Reynolds-averaged Navier-Stokes (RANS) equations with the renormalization group (RNG)
  - Commercial CFD code FLUENT 6.3.26

LTC Equation

- Local Pollutant Transfer Coefficient (LES only)

$$LPTC = <\overline{w}\,\overline{\phi}> + <w''\phi''> - <\alpha\frac{\partial\overline{\phi}}{\partial z}> - <\alpha_{sgs}\frac{\partial\overline{\phi}}{\partial z}>$$

  - Mean $<\overline{w}\,\overline{\phi}>$
  - Fluctuation $<w''\phi''>$
  - Molecular $<\alpha\frac{\partial\overline{\phi}}{\partial z}>$

$$Diffusivity = \frac{kinematic\quad viscosity}{Schmidlt\quad No.}$$

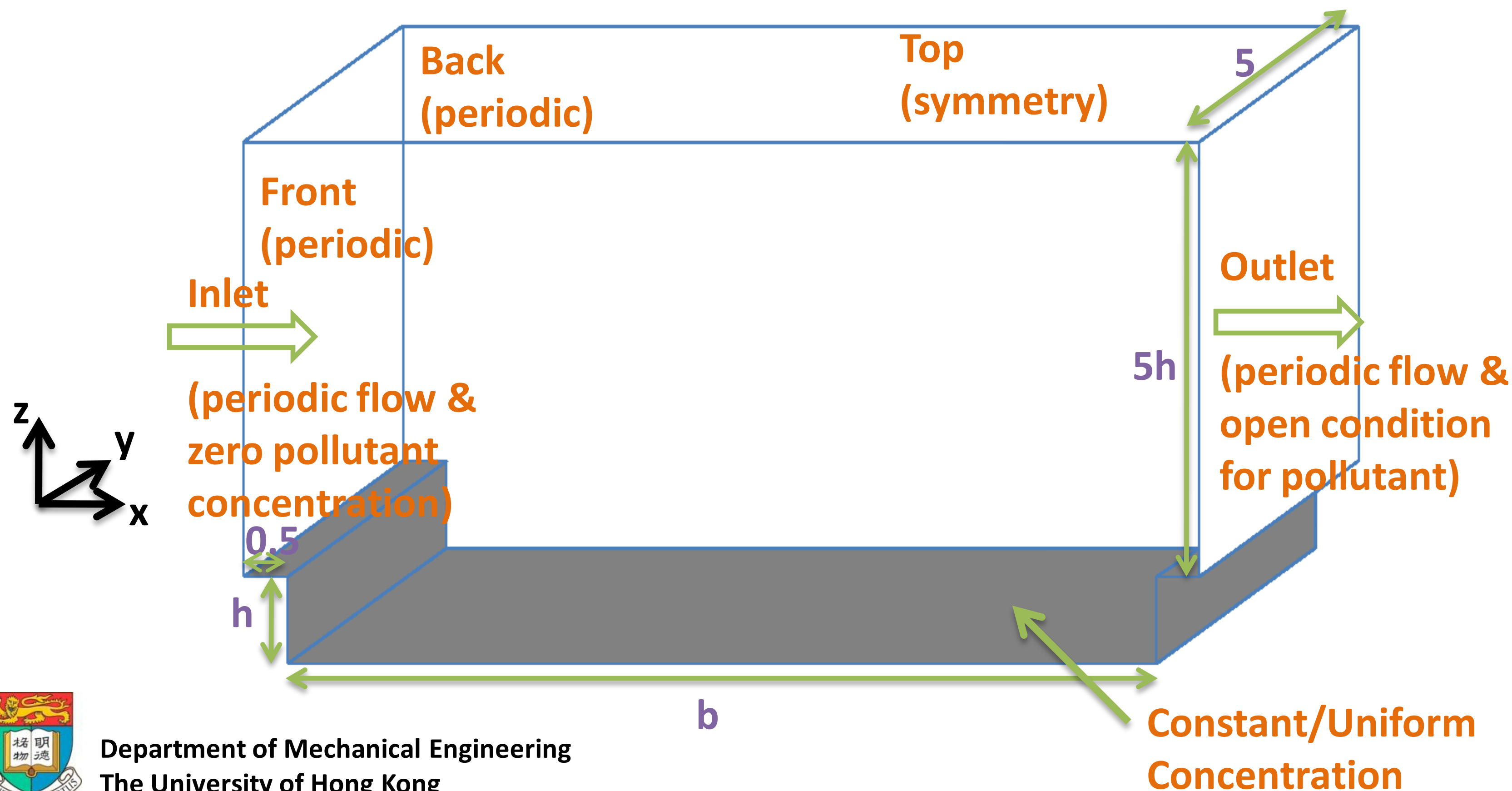
    - Kinematic viscosity ν (= 10^{-5})
    - Schmidlt No. (= 0.72)
  - Sub-grid scale $<\alpha_{sgs}\frac{\partial\overline{\phi}}{\partial z}>$

$$\nu_{sgs} = C_k k_{sgs}^{1/2}\Delta$$

- *k-ε* turbulence model
  - **NO** subgrid-scale term

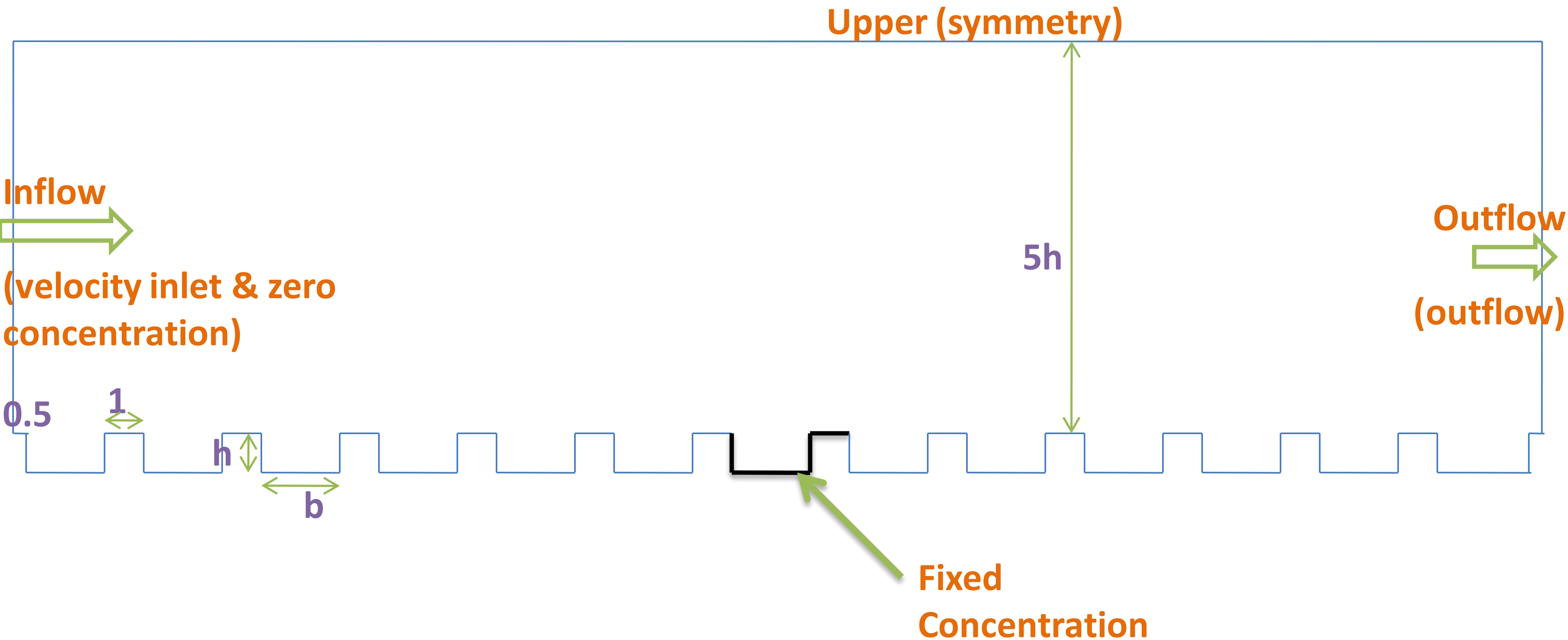
LES Model Description

- Domain of h = 1, b = 15 (AR = 0.0667), 11 (0.0909), 4 (0.25)



k-*ε* Turbulence Model Description

- Domain with h = 1, b = 15 (AR = 0.0667), 11 (0.0909), & 4 (0.25)



Model Validation

- Comparisons with Aliaga et al. (1994) results
- Nusselt Number $Nu = \frac{LTC \times H}{k}$ as the parameter
- Data reduction due to different Reynolds number

Convert LTC to Nusselt Number (Nu)

- Aliaga et al. (1994)

$$Nu_G = \frac{LHTC_G \times D_G}{k_G} = \frac{LHTC_G \times 0.025}{0.026} = 0.9615 LHTC_G$$

- LES

$$Nu_T = \frac{LPTC_T \times H_T}{\kappa_T} = \frac{LPTC_T \times 1}{10^{-5} / 0.72} = \frac{LPTC_T}{1.389 \times 10^{-5}}$$

Reynolds Number (Re)

Aliaga et al. (1994)

$$\mathrm{Re}_G = \frac{U_G D_H}{\nu}$$

$$\nu = 10^{-5} kgm^{-1}s^{-1}$$

- AR = 0.25 = 1/4

$$U_G = 32 m/s$$
$$D_H = 0.025 m$$

- AR = 0.0909 = 1/11

$$U_G = 38 m/s$$
$$D_H = 0.025 m$$

LES

$$\mathrm{Re}_T = \frac{U_T H_T}{\nu}$$

$$\nu = 10^{-5} kgm^{-1}s^{-1}$$

- AR = 0.25 = 1/4

$$U_T = 1.01715 m/s$$
$$H_T = 1m$$

- AR = 0.0909 = 1/11

$$U_T = 1.27123 m/s$$
$$H_T = 1m$$

Normalized Nusselt Number (Nu/Re^m)

$$Nu = C \, \mathrm{Re}^m \, \mathrm{Pr}^n$$

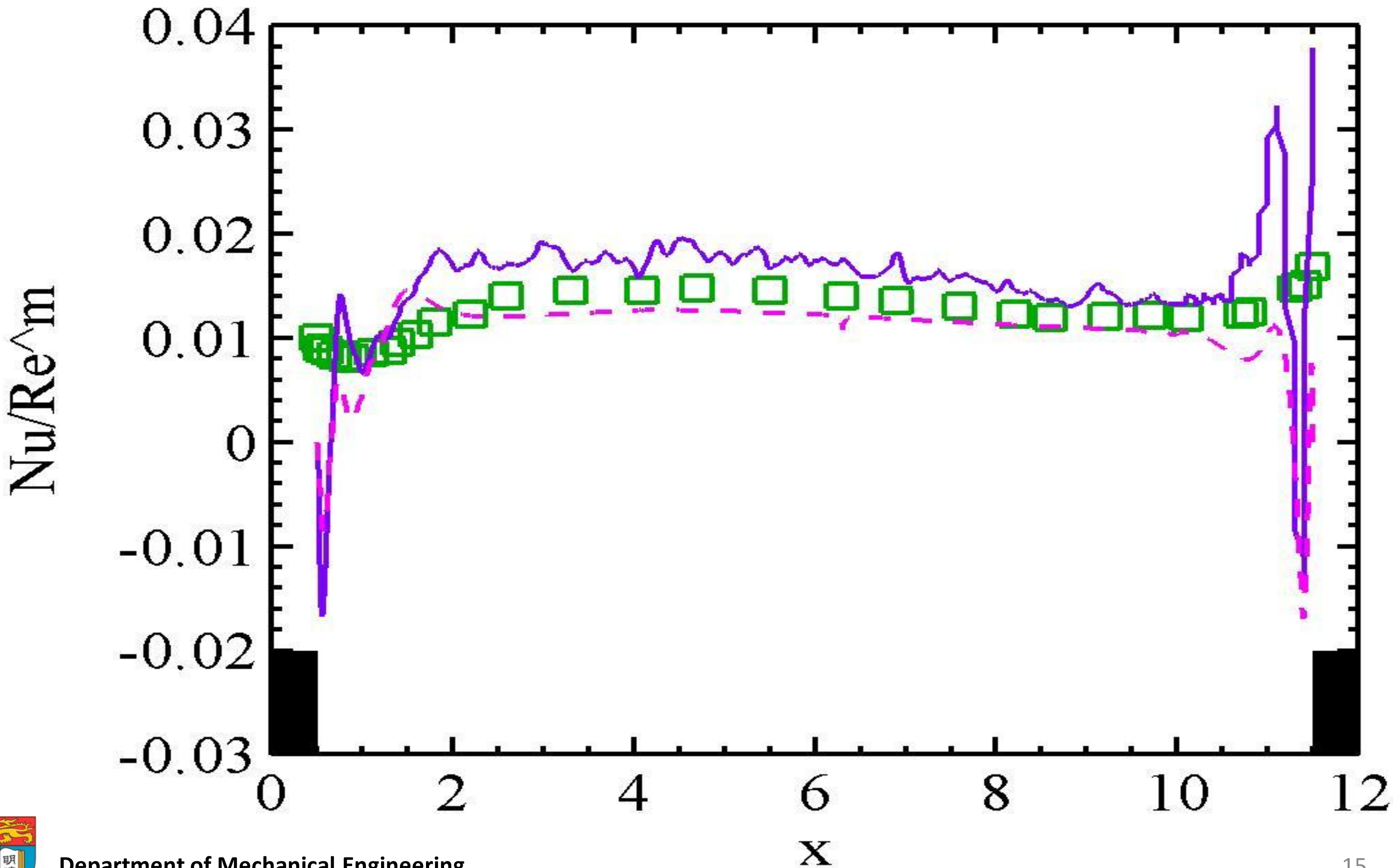
$$C, \mathrm{Pr}, n = Const$$

$$m = 4/5$$

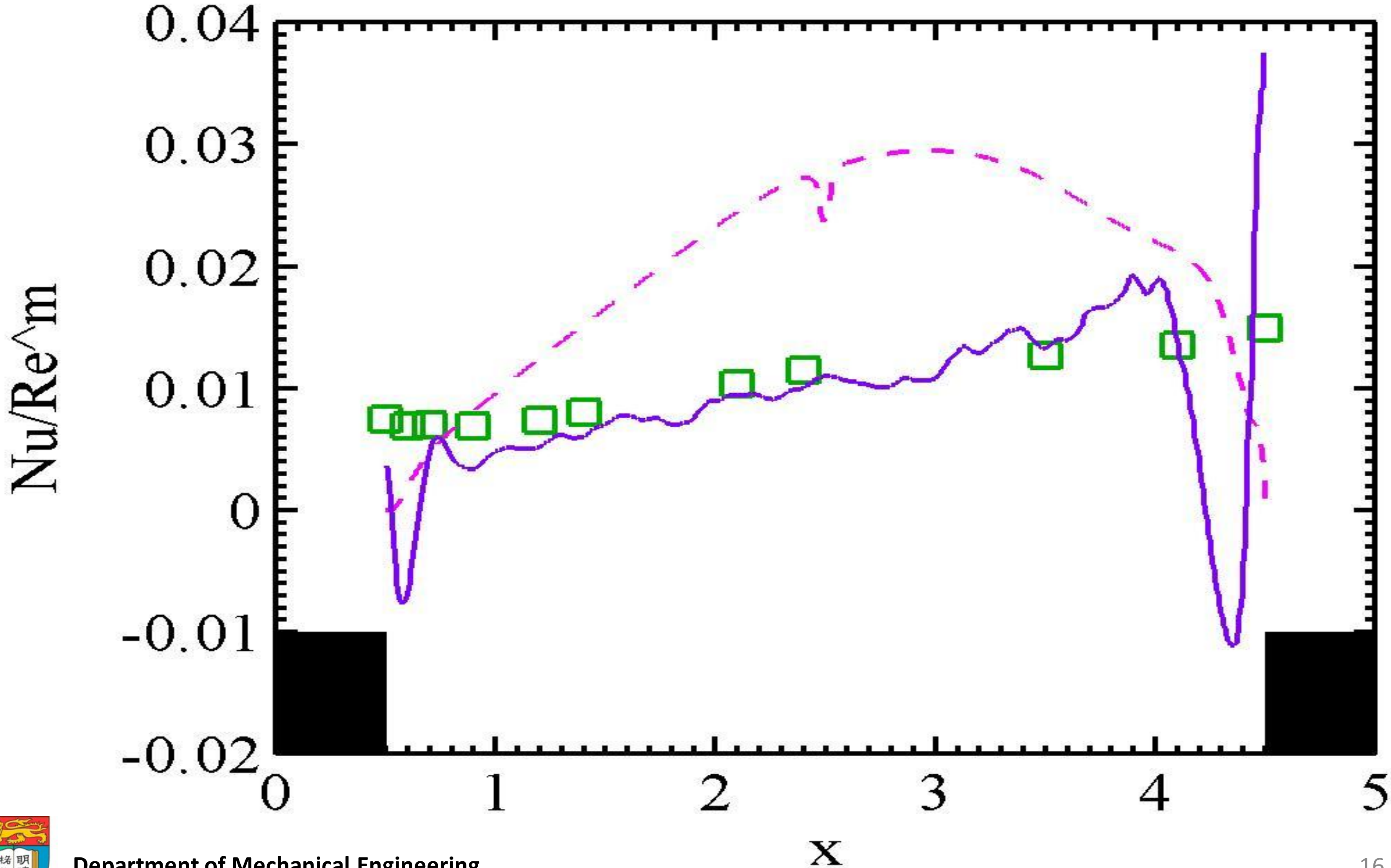
$$Nu \propto \mathrm{Re}^{4/5}$$

$$\frac{Nu}{\mathrm{Re}^{4/5}} = CONSTANT$$

Model Validation (AR = 0.0909 = 1/11)

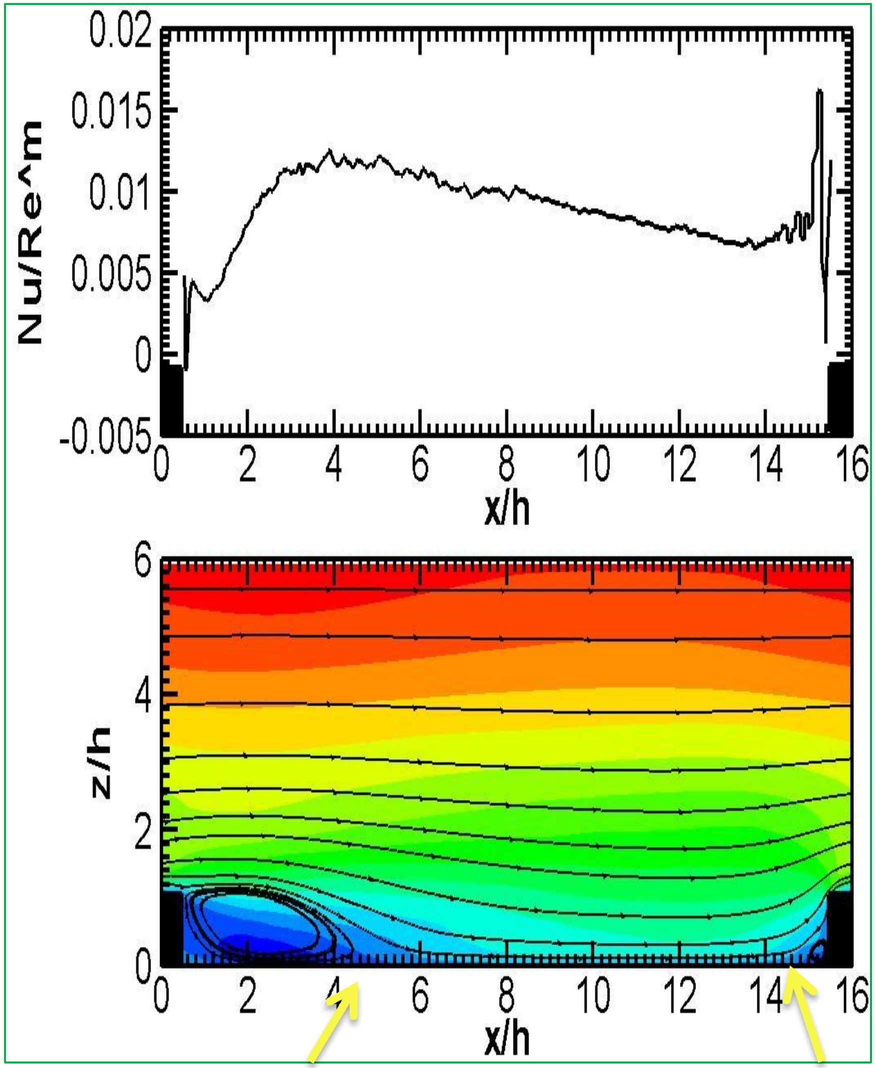


Model Validation (AR = 0.25 = 1/4)

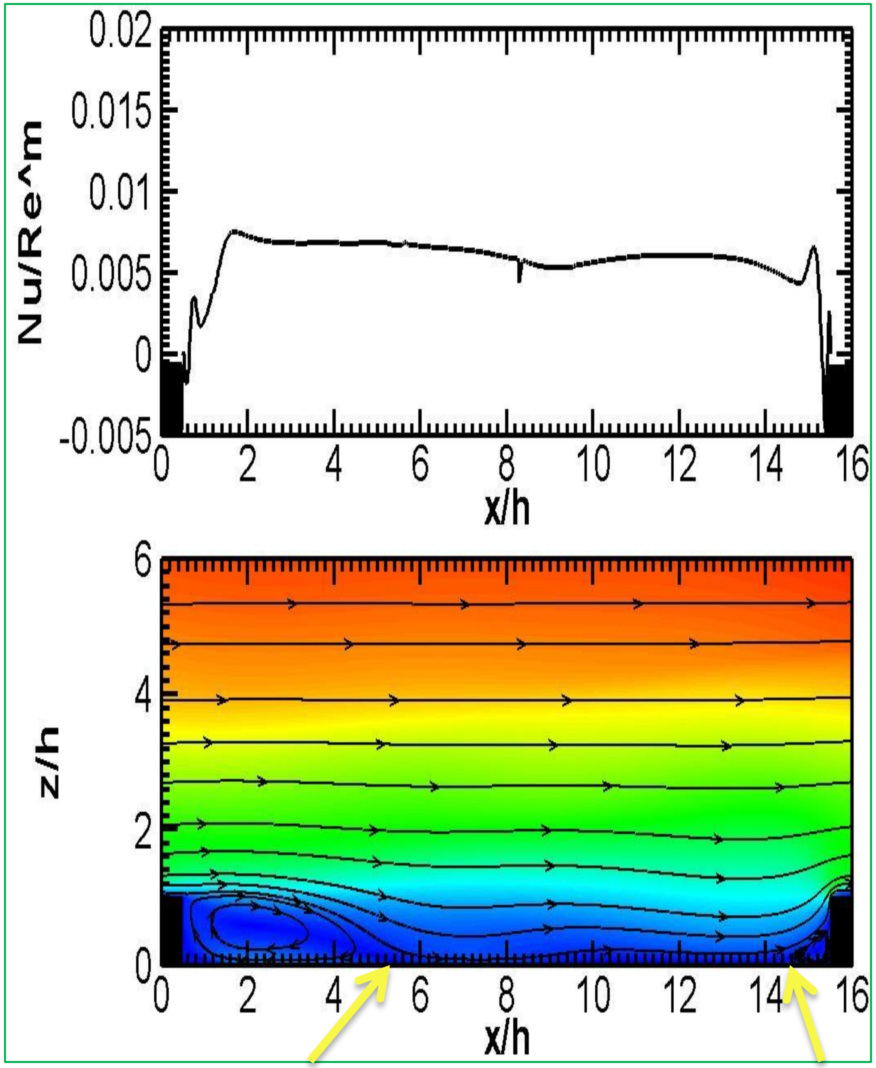


CFD Results (AR = 0.0667 = 1/15)

LES simulation



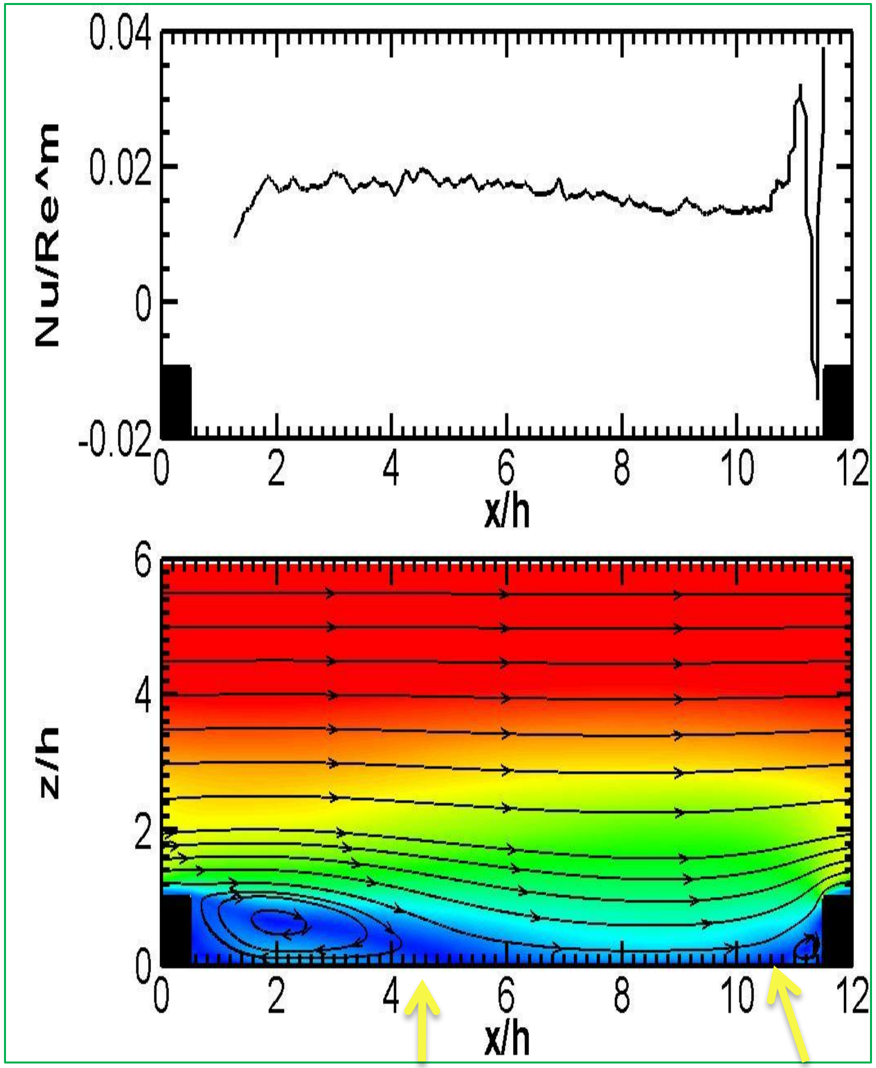
***k-ε* turbulence model**



Reattachment Separation Reattachment Separation

CFD Results (AR = 0.0909 = 1/11)

LES simulation



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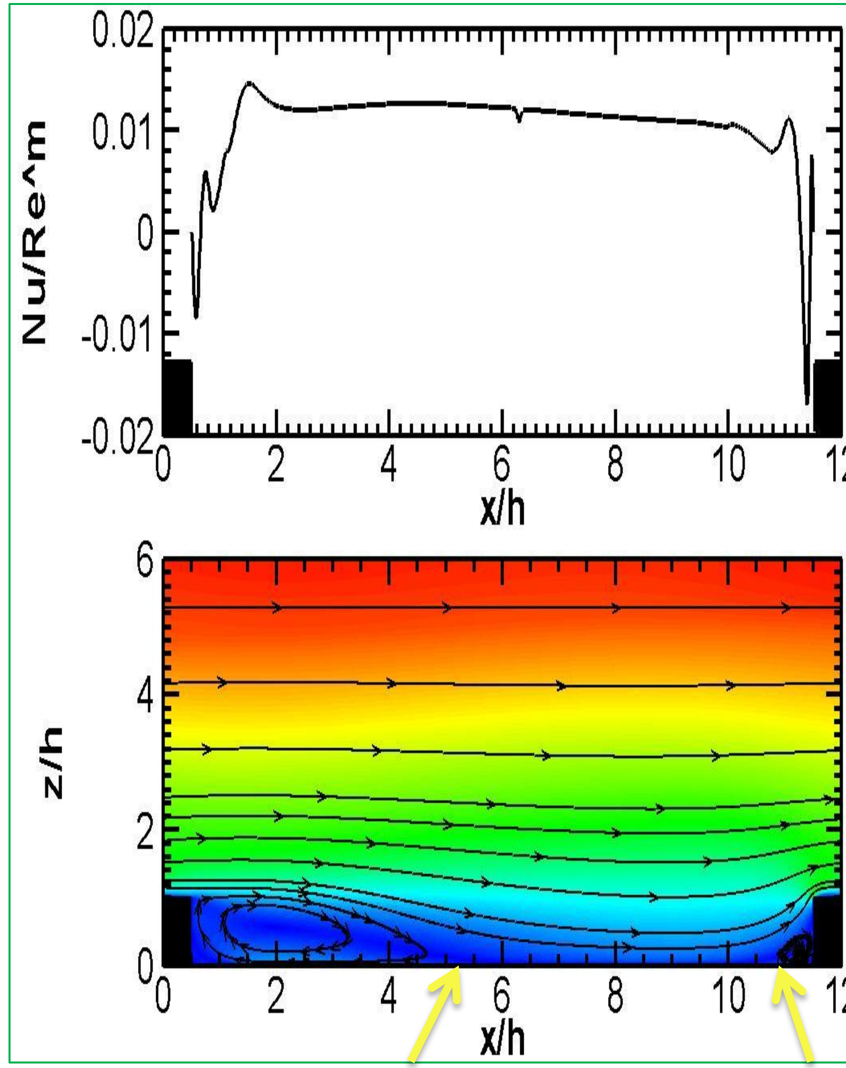

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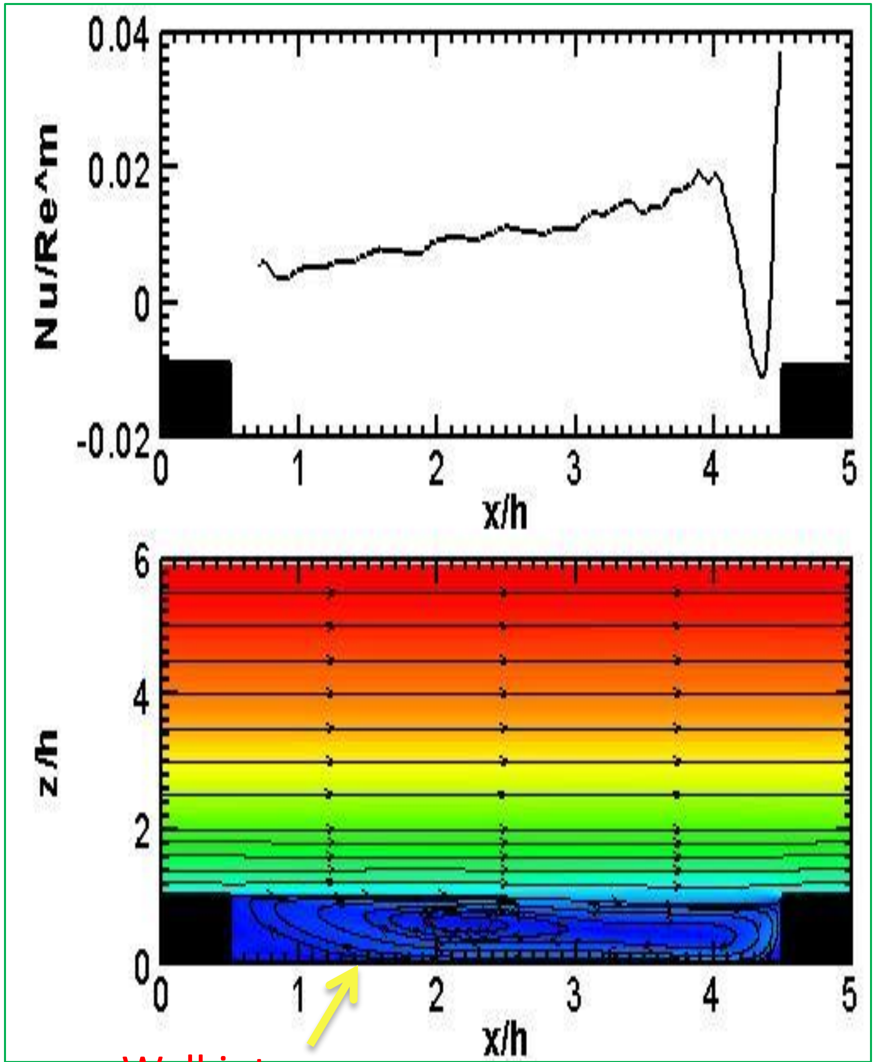
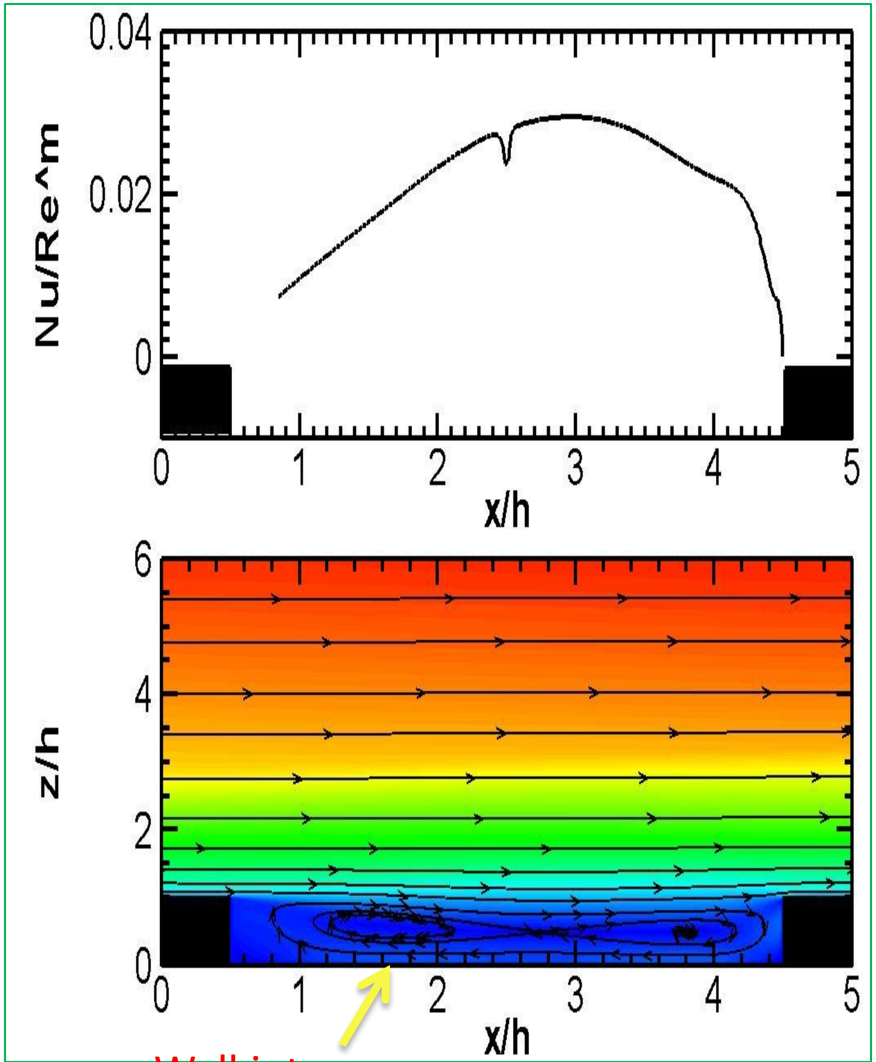


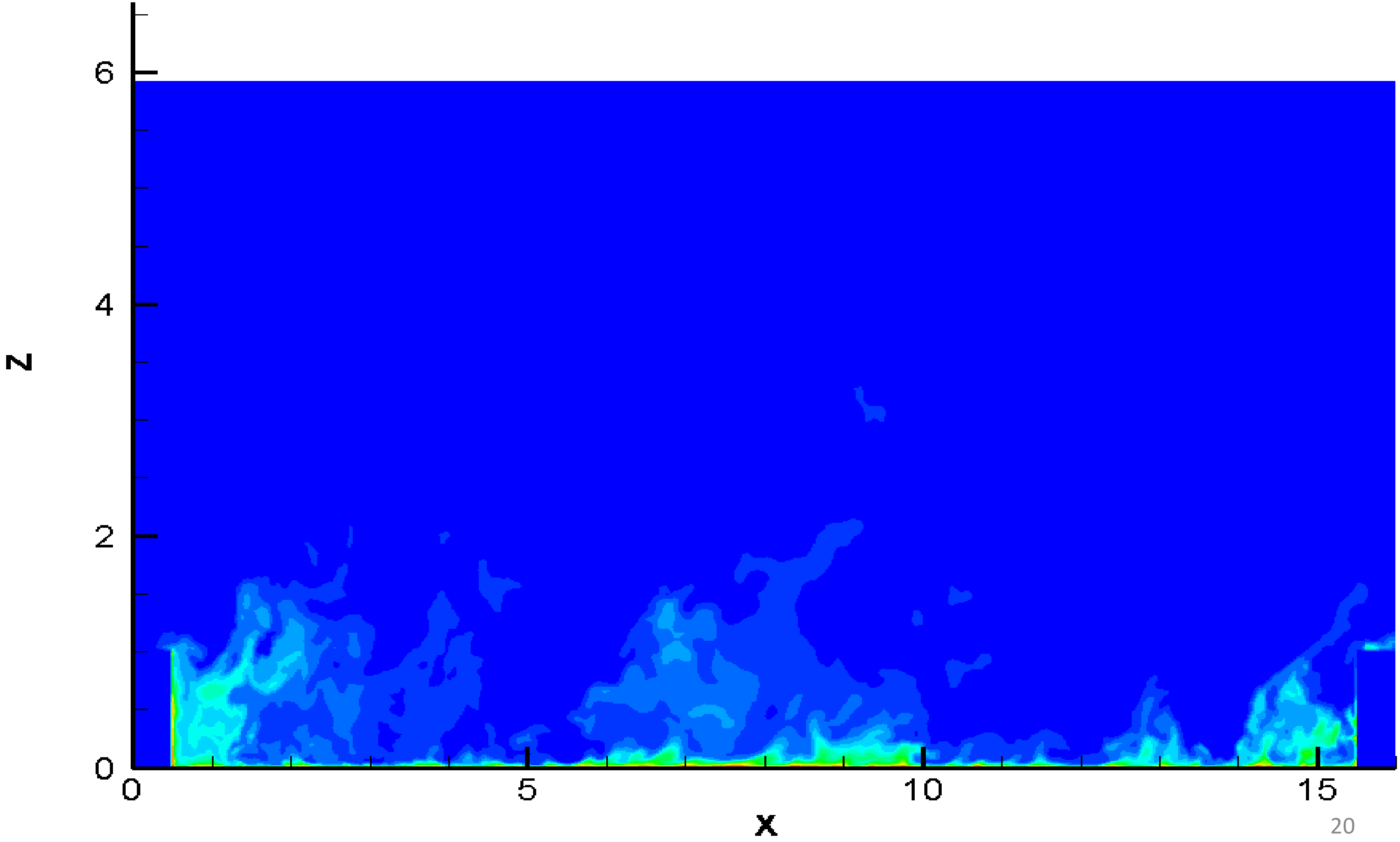
Wall jet

***k-ε* turbulence model**

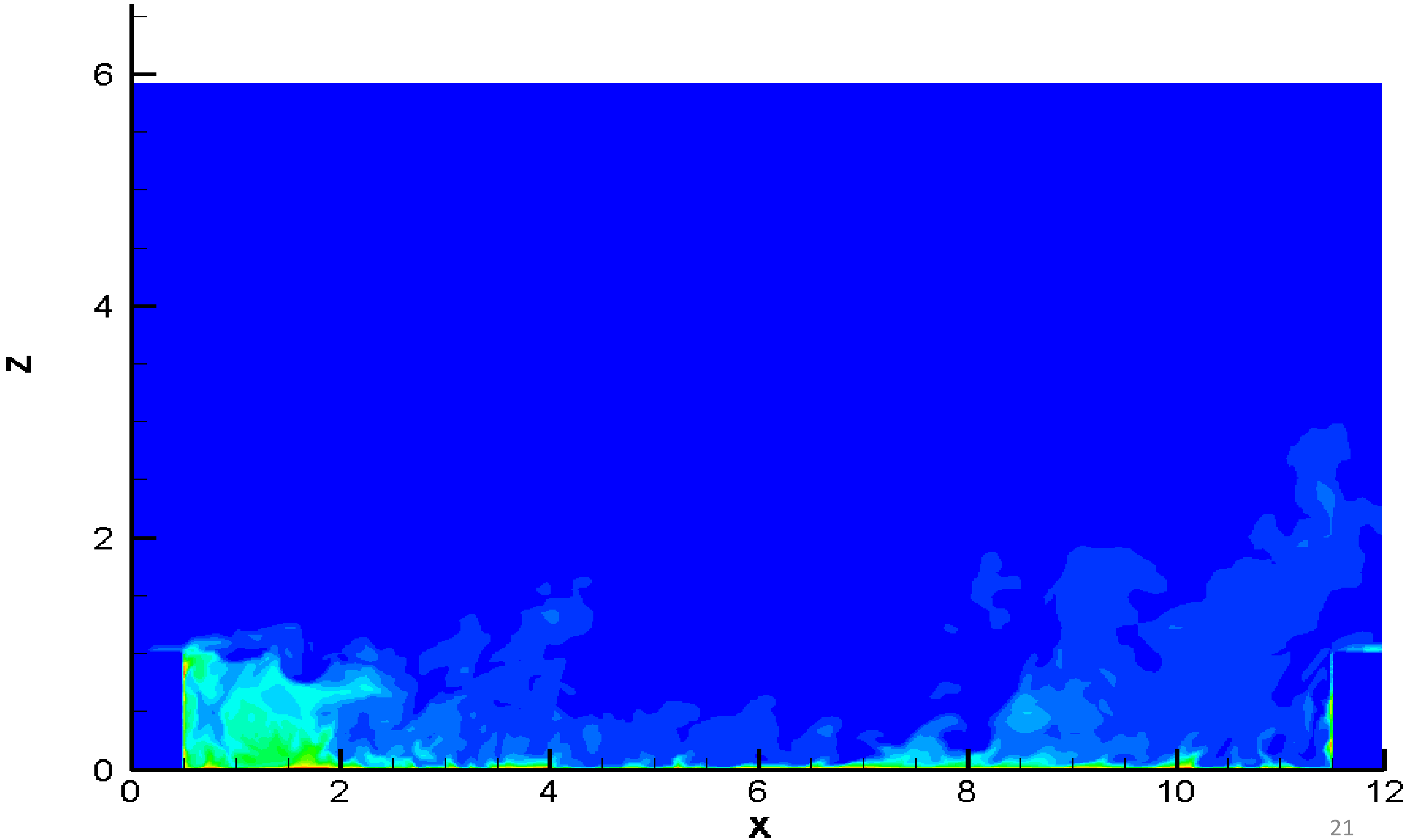


Wall jet

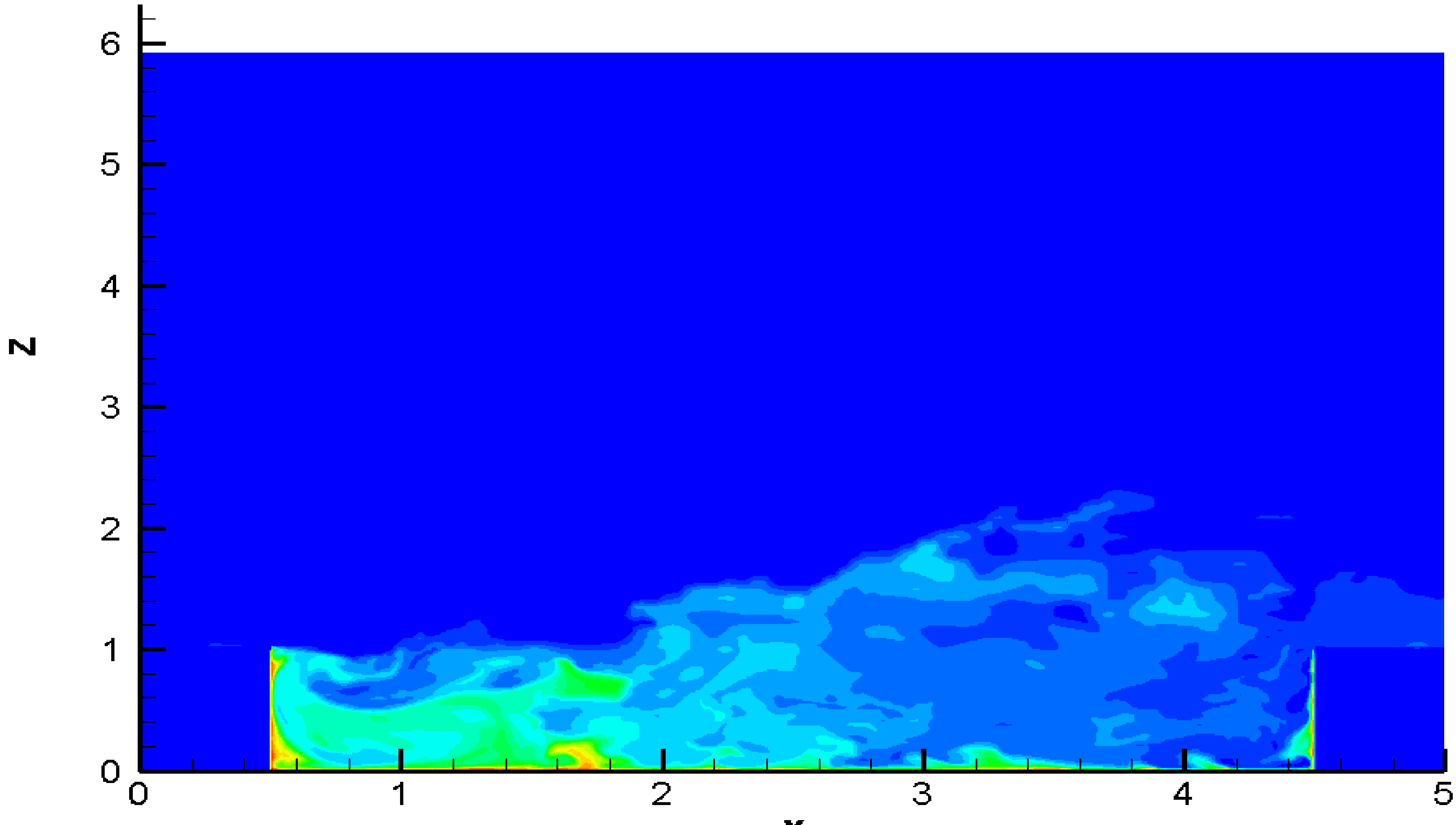
Roof-level Pollutant Removal (AR = 0.0667 = 1/15)



Roof-level Pollutant Removal (AR = 0.0909 = 1/11)



Roof-level Pollutant Removal (AR = 0.25 = 1/4)



Conclusion

- Relationship between flow regimes & pollutant transfer coefficient
  - Isolated roughness regime
    - Maximum local pollutant transfer coefficient: Reattachment point
    - Minimum local pollutant transfer coefficient: Separation point
  - Wake interference regime
    - Increasing local pollutant transfer coefficient from leeward side to windward side
- Roof level Pollutant Removal Mechanisms
  - Isolated roughness regime
    - Fresh air entrainment from the shear layer down to the street canyon
  - Wake interference regime
    - Turbulent diffusion through the roof level

References

- Oke, T.R., 1988: Street design and urban canopy layer climate: *Energy and Buildings*, **11(1-3)**, 103-113.
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