Three canonical flows, one geometry

Study Of the Turbulent Flow Structure in an Annular Space with Inter-rod Gapping

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2nd April 2014

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Code_Saturne User Meeting

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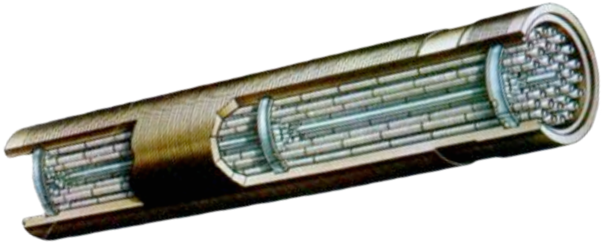
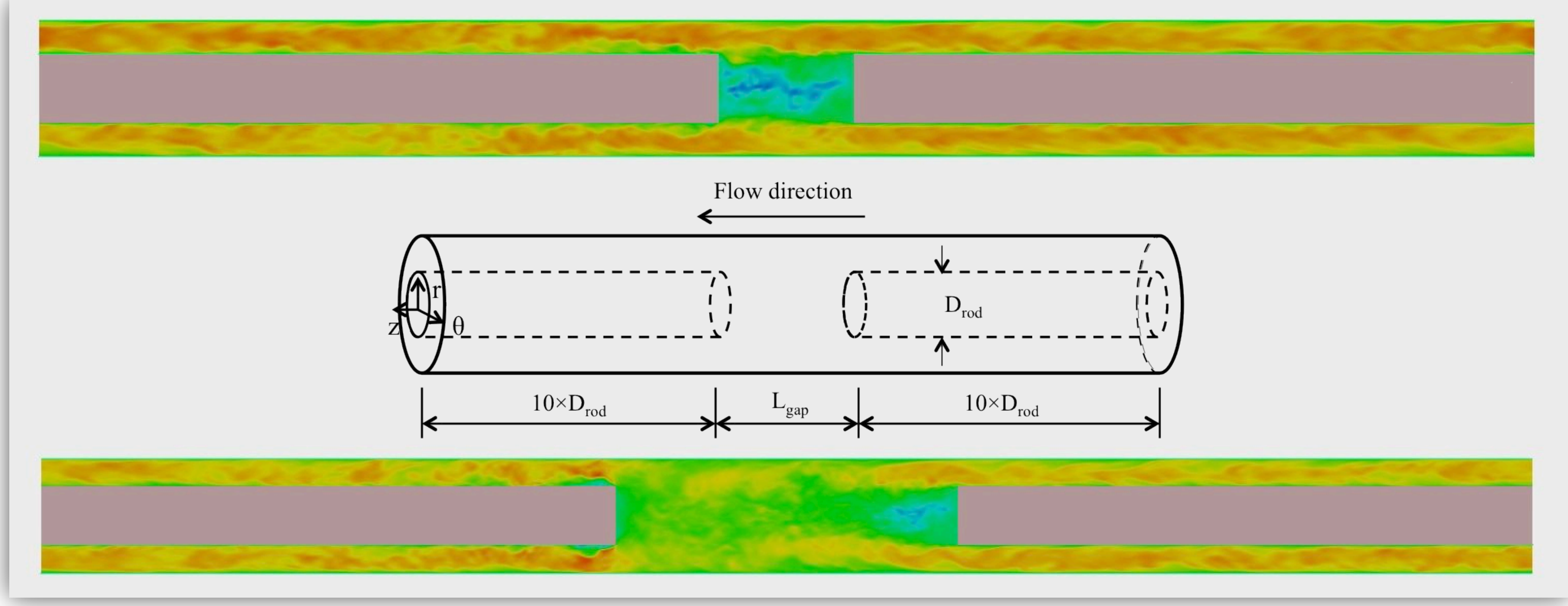
Motivation

A fundamental investigation using LES of the flow structure between fuel rods as a potential source of the flow induced vibration phenomenon within the fuel elements of a **nuclear** reactor





Computational Details

Large Eddy Simulation

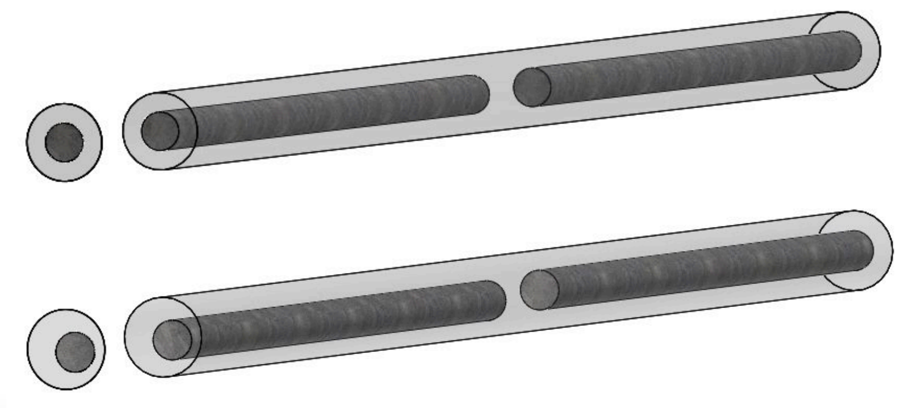
- Wall resolved LES ➔ No wall function
- Dynamic Smagorinsky sub-grid scale model ($\nu_{sgs}>0$)
- 2nd order schemes in space and time:
  - pure centred in space
  - mix of Crank-Nicolson and Adams-Bashforth in time
- CFL number < 1
- $Re = (U_{bulk} \times D_{rod})/\nu \approx 12000$

3 Configurations considered:

① Basic annulus

② Concentric Configuration

③ Eccentric Configuration



Inlet Methods

① Periodic

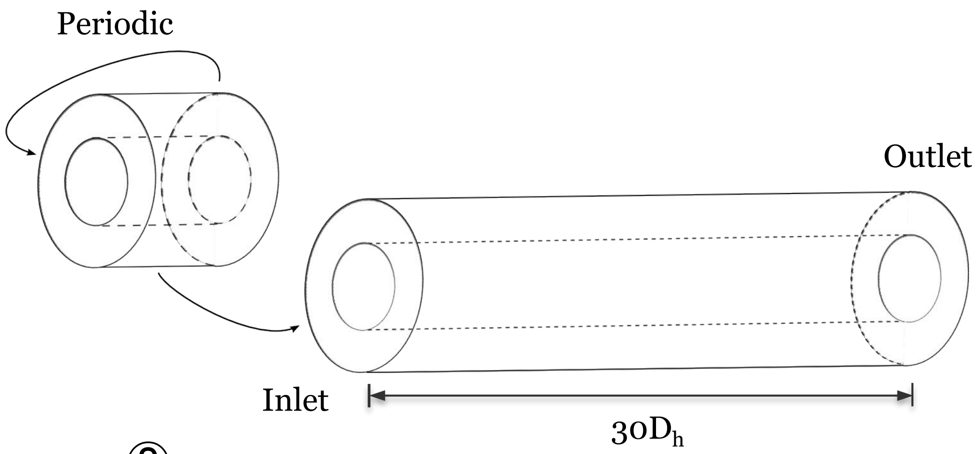
② Precursor

- Couple two domains
- Specify velocity from periodic domain to the Inlet

③ Recycling

- Map velocity from a downstream plane to the Inlet
- Rescale by Q_{in}/Q_{cyc}

✧ Initialisation by SEM used in all 3 cases



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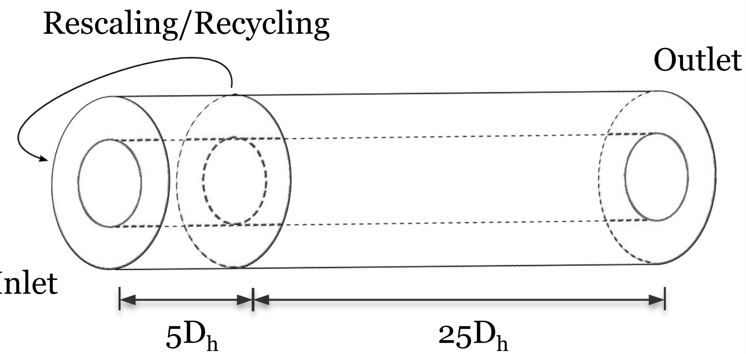

③

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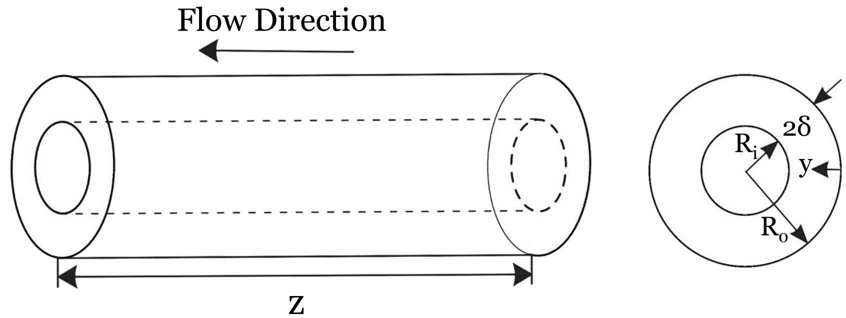
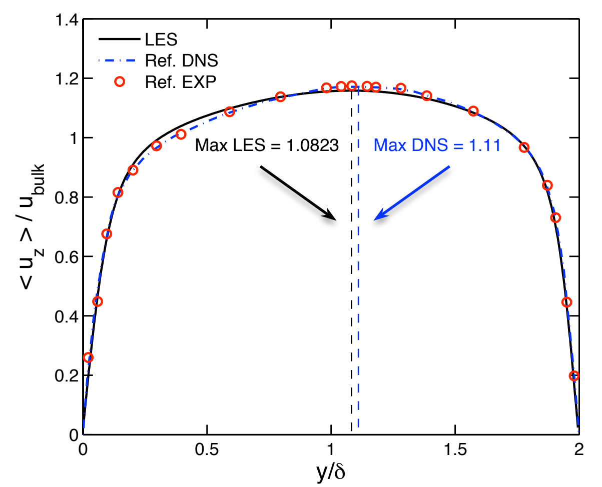
Inlet Methods

- Basic annulus used for inlet method comparison
- Good agreement with DNS by Chung *et al.* using periodic boundary conditions

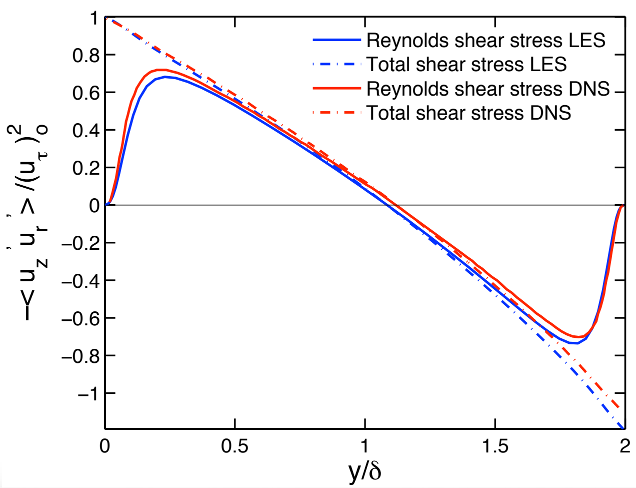


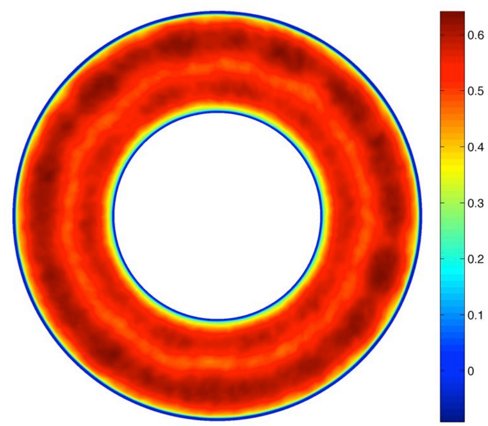
$$\frac{\varepsilon_{sgs}}{\varepsilon+\varepsilon_{sgs}} = \frac{\left\langle u_i' \frac{\partial \tau_{jk}}{\partial x_k} + u_j' \frac{\partial \tau_{ik}}{\partial x_k} \right\rangle}{-2\nu \left\langle \frac{\partial u_i'}{\partial x_k} \frac{\partial u_j'}{\partial x_k} \right\rangle + \left\langle u_i' \frac{\partial \tau_{jk}}{\partial x_k} + u_j' \frac{\partial \tau_{ik}}{\partial x_k} \right\rangle}$$

Mean Velocity



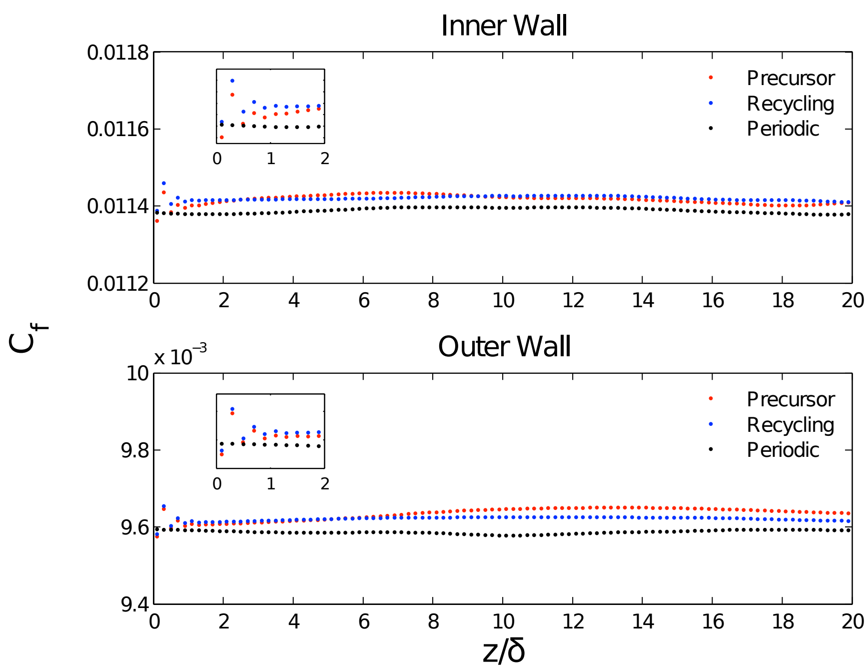
Shear stress

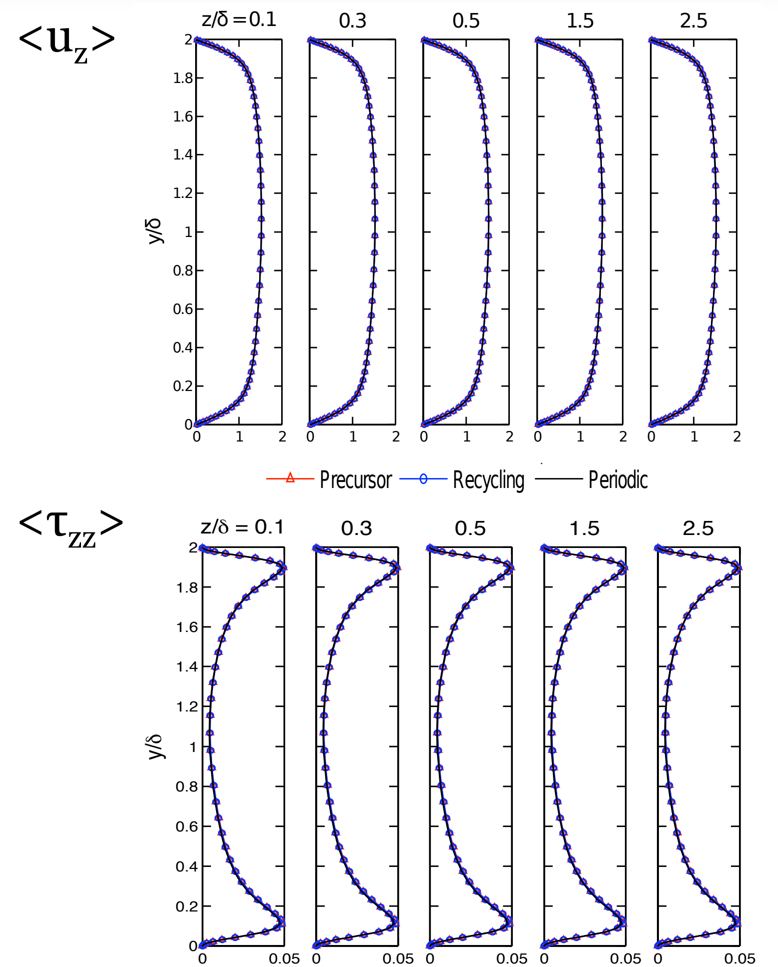




Inlet Methods

- Excellent agreement between first and second order statistics
- Friction Coefficient shows development region <2δ from the inlet





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Inlet Methods

- Certain budget terms show an adjustment section close to the inlet
- Precursor and Recycling method feature the same trends
- Profiles from other budget terms show excellent agreement

Turbulent Diffusion

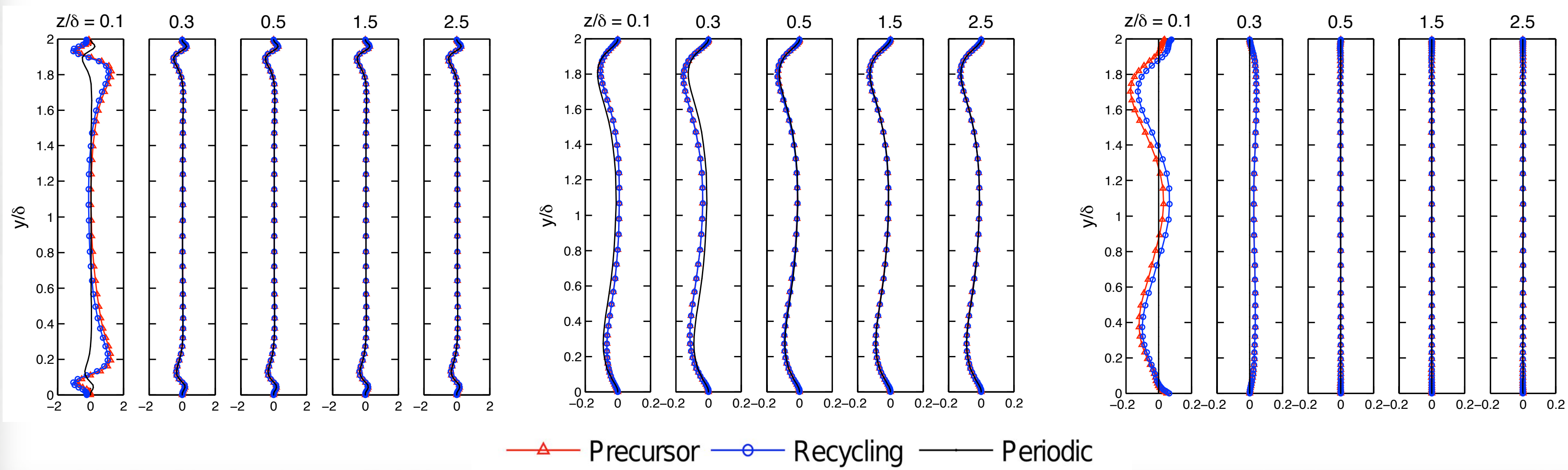
$$-\partial\langle u_i' u_j' u_k'\rangle/\partial x_k$$

Pressure Strain

$$1/\rho \ \langle p'\left(\partial u_i'/\partial x_j + \partial u_j'/\partial x_i\right)$$

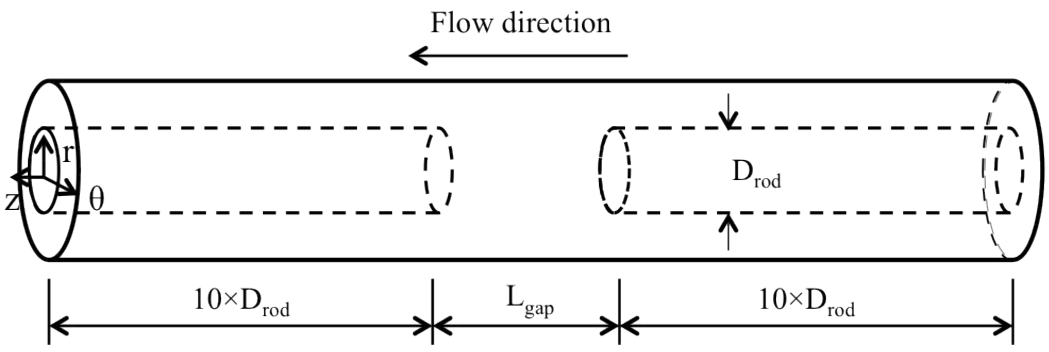
Pressure Diffusion

$$-1/\rho \ \left(\partial\langle u_j' p'\rangle/\partial x_i + \partial\langle u_i' p'\rangle/\partial x_j\right)$$

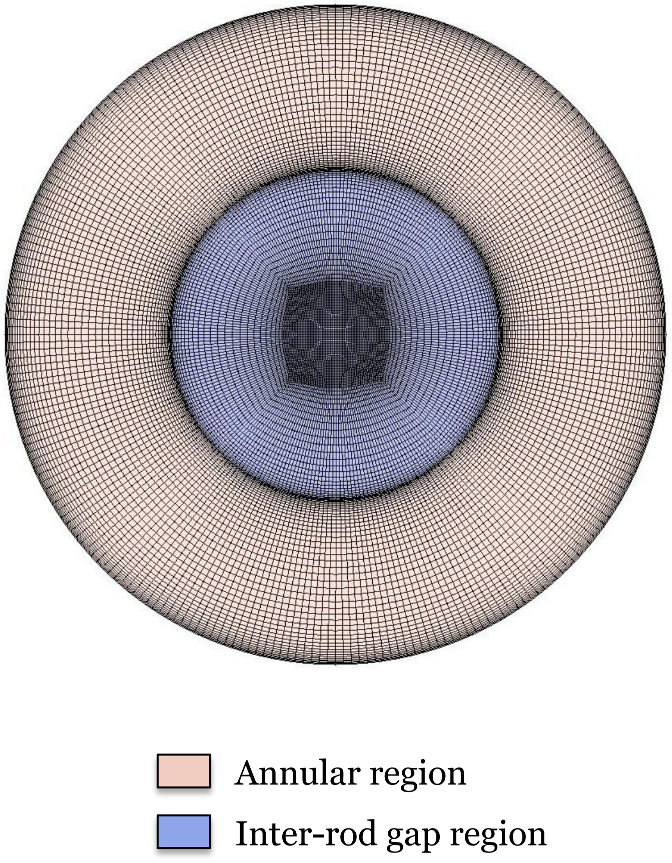


Concentric Gap Case

- Two cases:
  1. **"6D case"**: $L_{gap} = 6 \times D_{rod}$
  2. **"2D case"**: $L_{gap} = 2 \times D_{rod}$
- Fully conforming hexahedral, block-structured grid
- $\Delta r^+ \approx 1$, $r\Delta\theta^+ < 15$, $\Delta z^+ < 35$

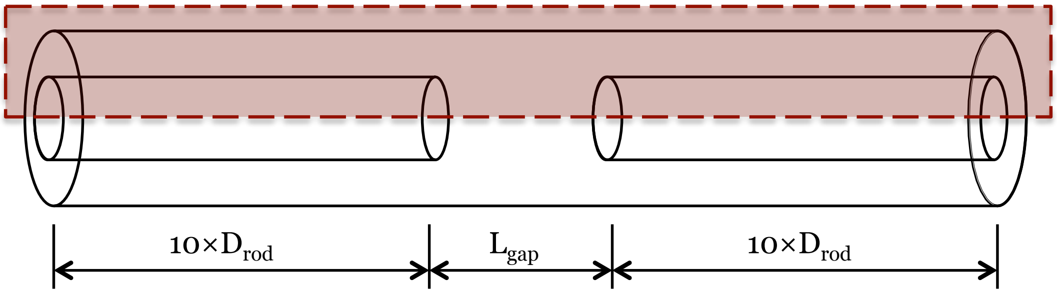


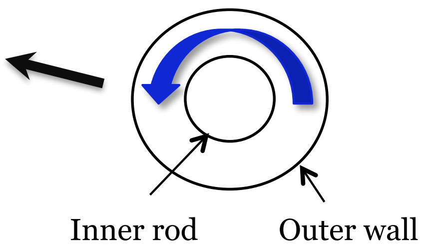
Schematic diagram of computational domain



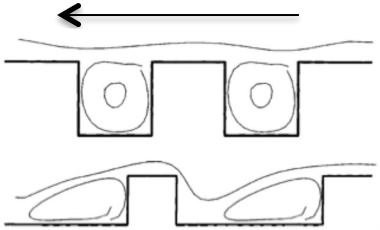
Concentric Gap Case

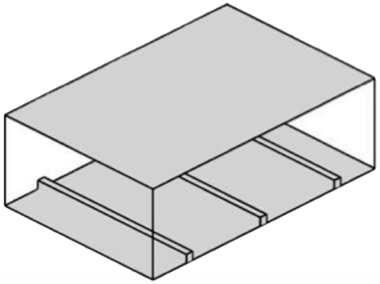
- Flow statistics
  - Flow is axisymmetric ➔ Average in time and in the azimuthal direction
  - $\Delta t_{ave} \approx$ *10 and 30 flow through times*





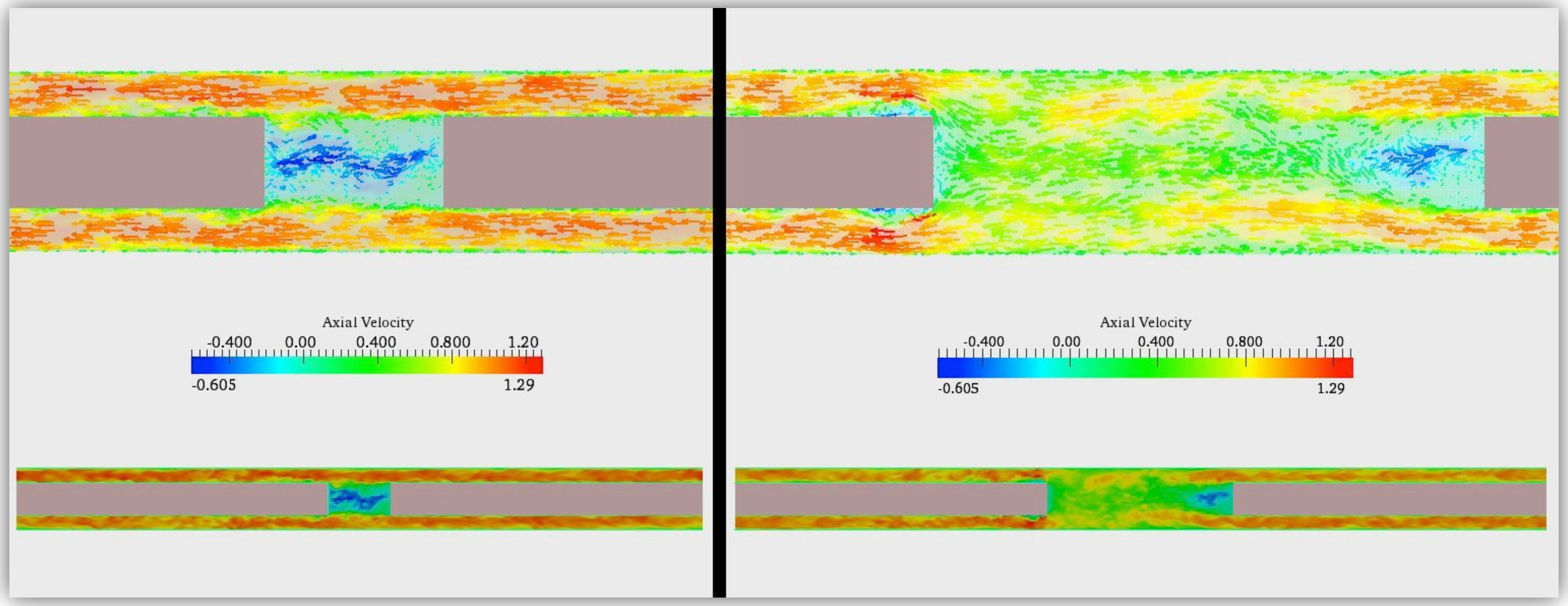
- Flow over rough walls
  - *d*-type
  - *k*-type



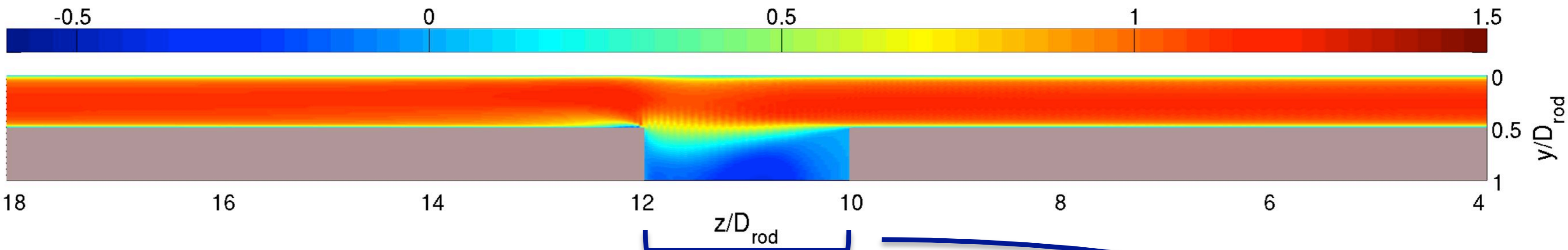


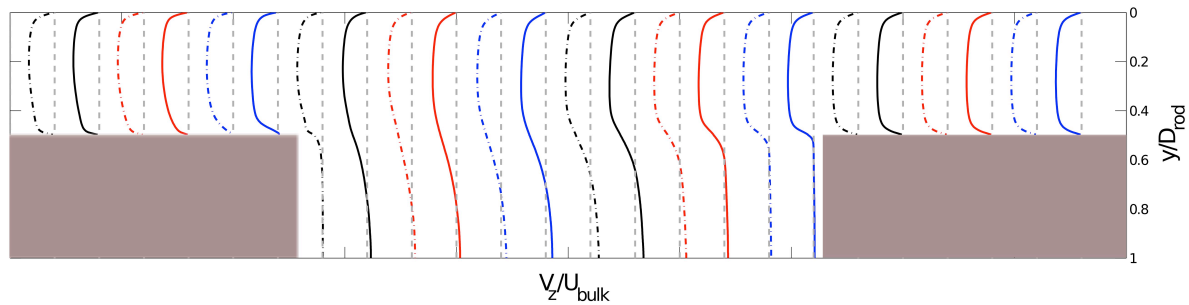
Concentric Gap Case

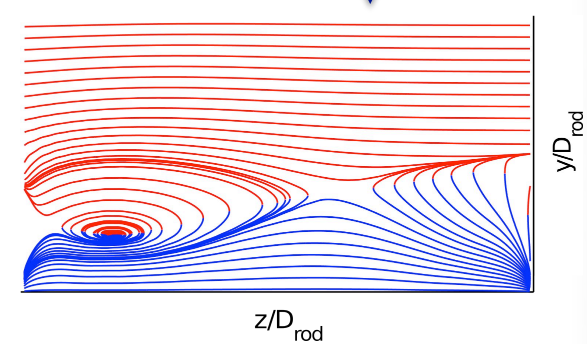
2D Case **6D case**



Mean Axial Velocity – 2D case







Velocity Particle Trajectories in gap

Positive direction
Negative direction

- Two distinct flow regions
- Strong interaction between main flow and gap flow
- Strong flow reversal in the gap
- Flow pattern is analogous to flow over *d*-type roughness

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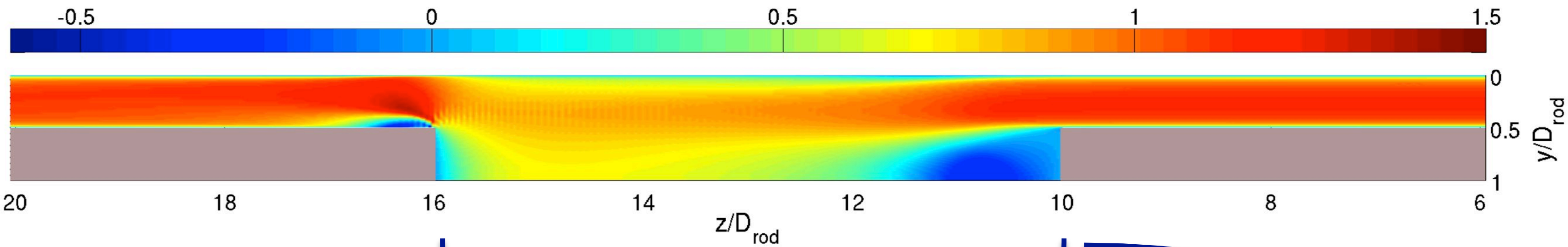
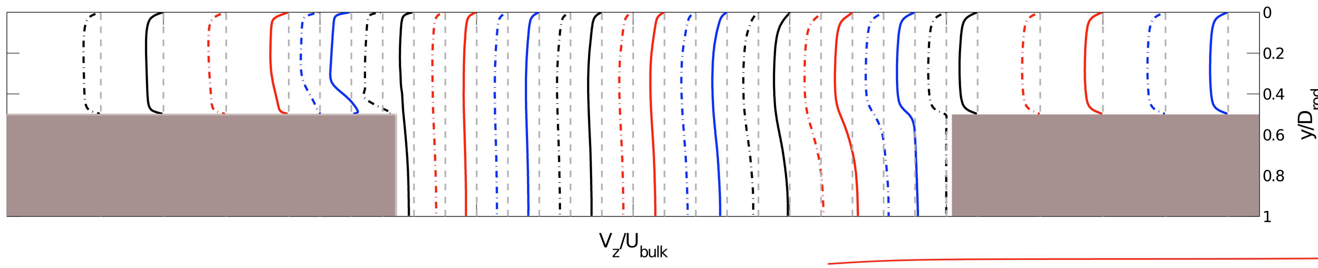
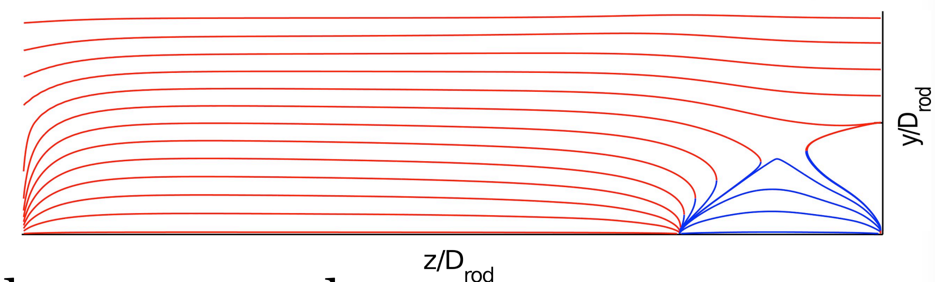
Mean Axial Velocity – 6D







- New flow development in gap
- Recirculation length in proximity of upstream rod ≈ $1.5 \times D_{rod}$
- Significant separation bubble along downstream rod
- Flow pattern is akin to flow over *k*-type roughness

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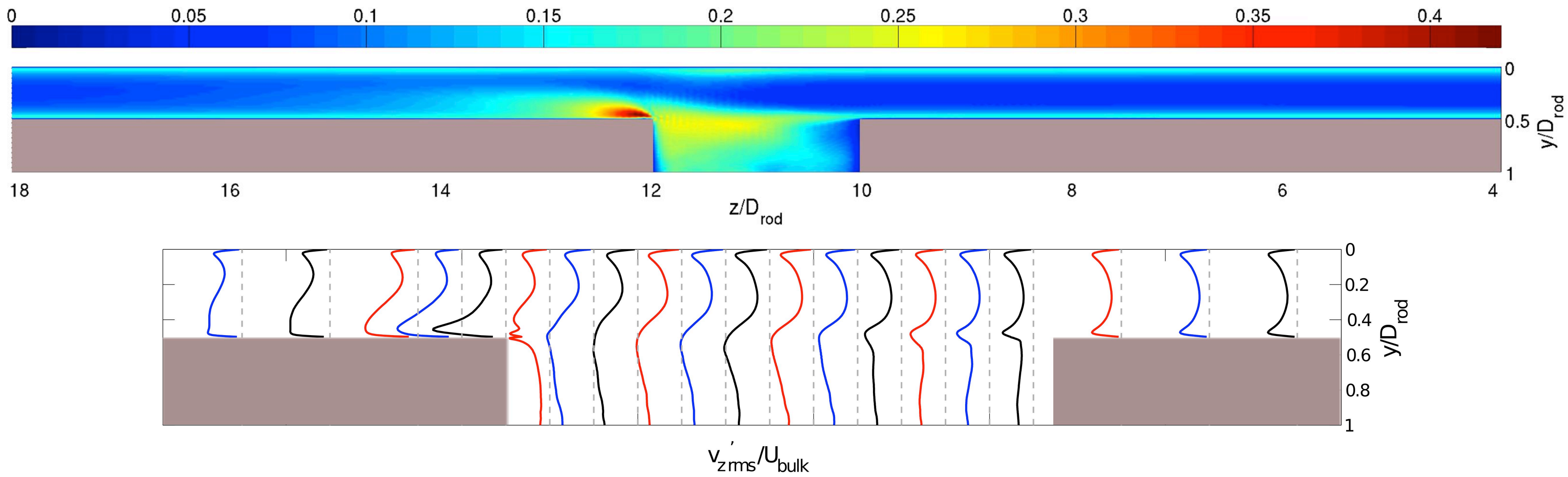
Streamwise Turbulence Intensity

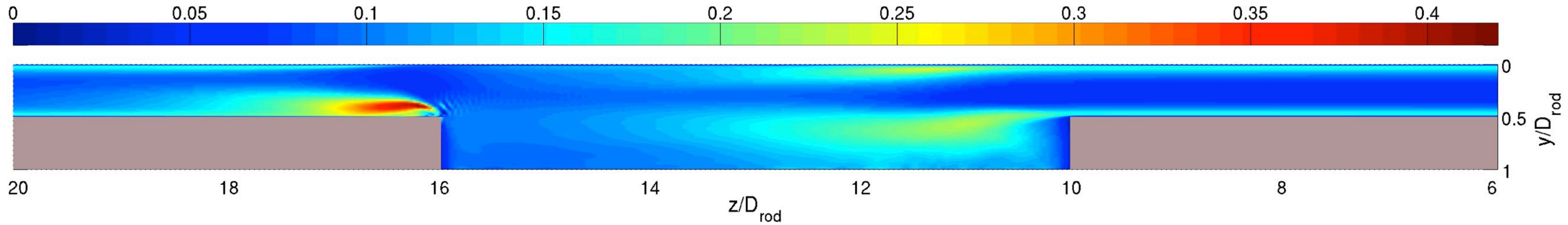
2D Case

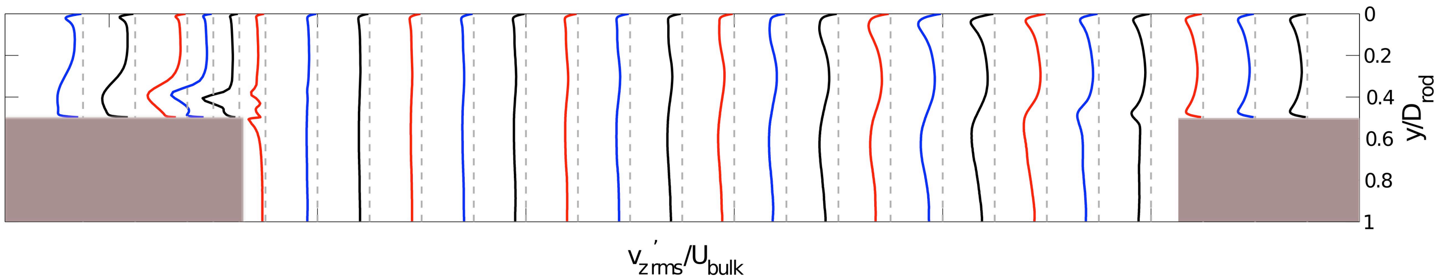


- Main flow remains wall shear flow throughout
- Shear layer at the interface is maintained for a short distance into the gap and then new turbulence is generated
- New turbulence is generated along the edge of the second rod

Streamwise Turbulence Intensity

6D case





- Wall shear flow continues for a short distance ➔ wall jet
- In the gap, initial jet flow is replaced by newly developed flow
- Strong turbulence is generated along the edge of the second rod as flow re-enters the annulus

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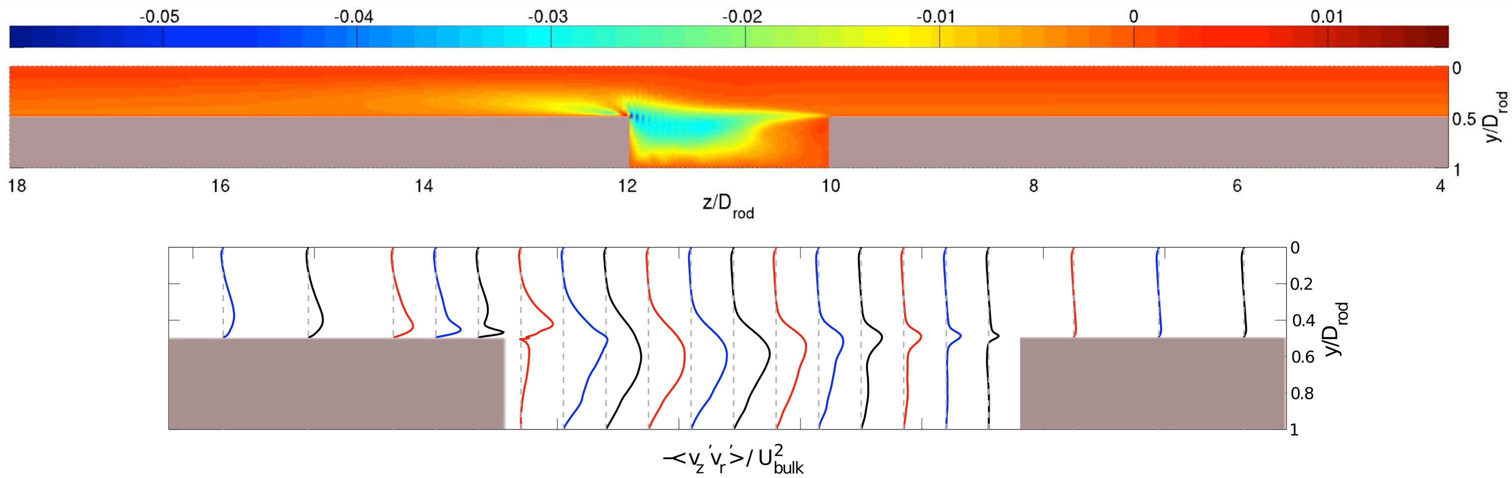
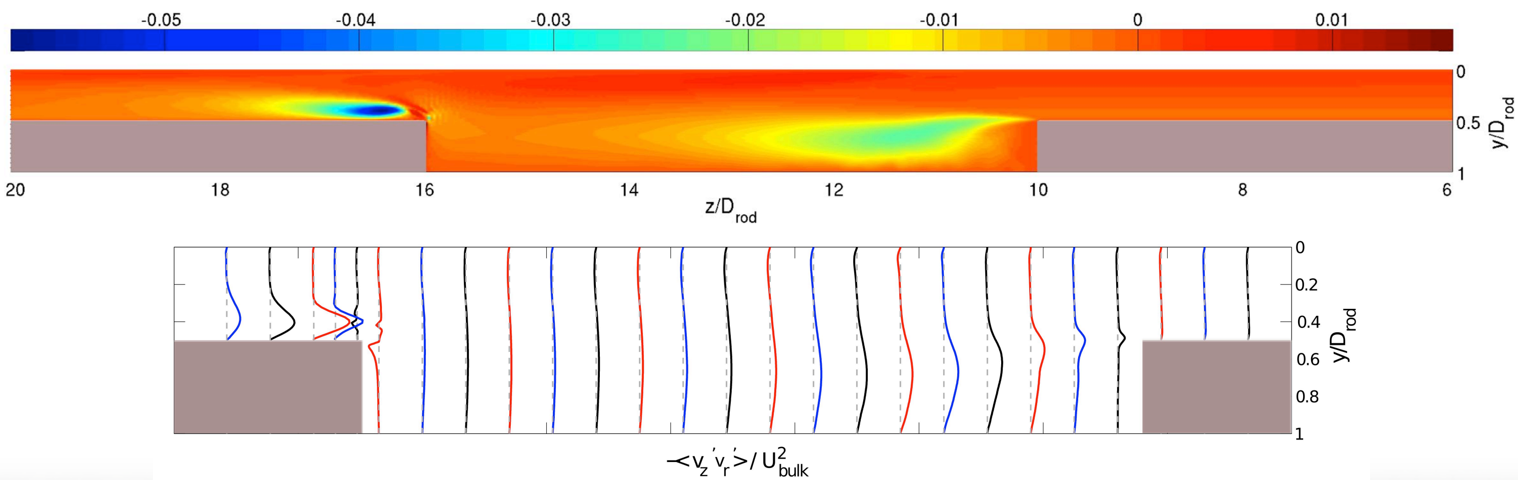
Reynolds Shear Stress

2D Case



6D case



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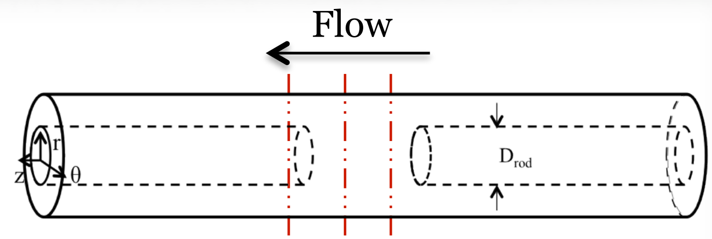
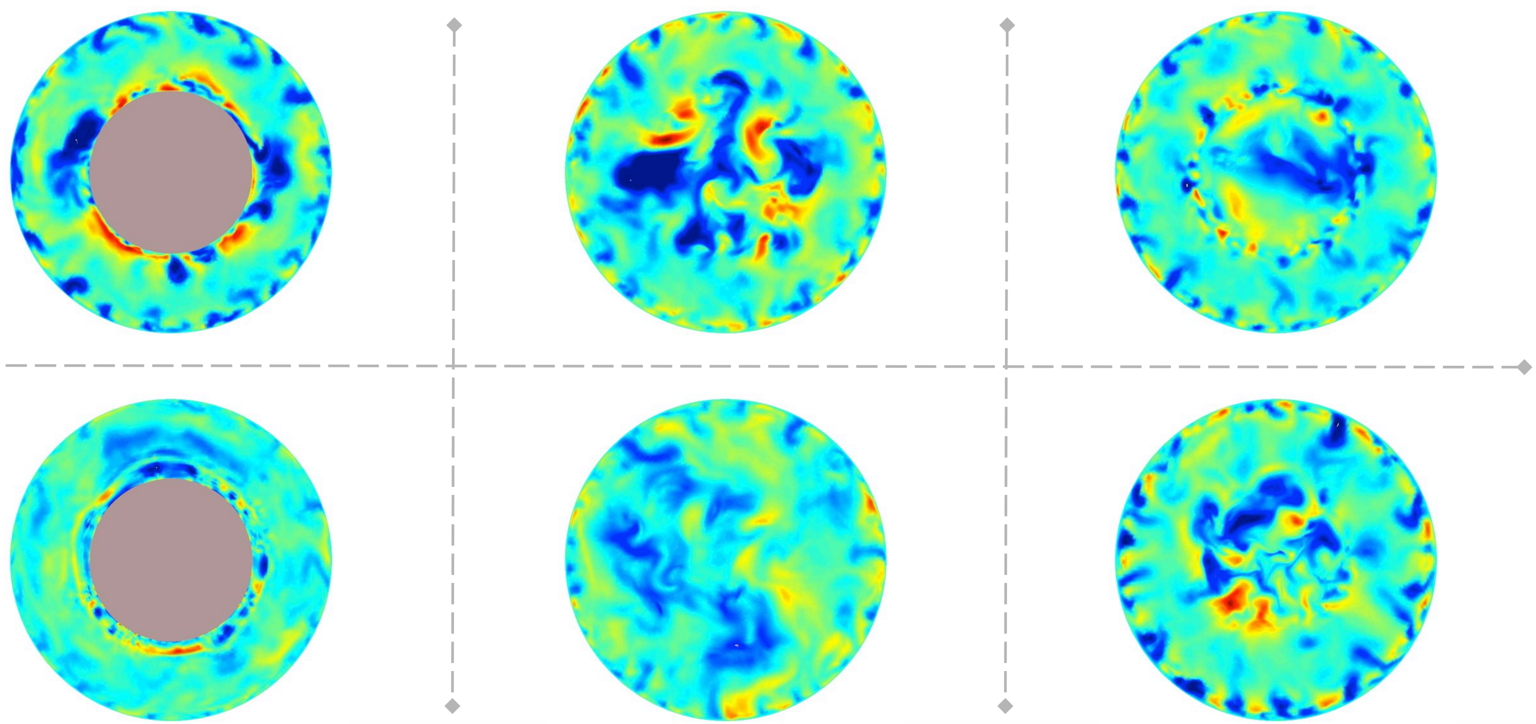
Axial Fluctuating Velocity

- Different flow behaviour at equivalent axial locations relative to the upstream rod



2D Case

6D case



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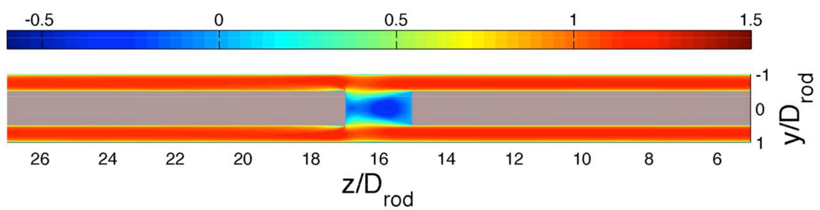
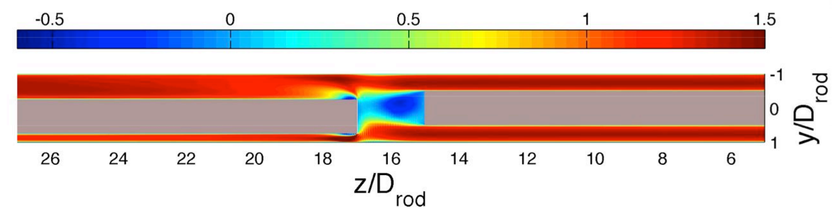
Eccentric Gap Case

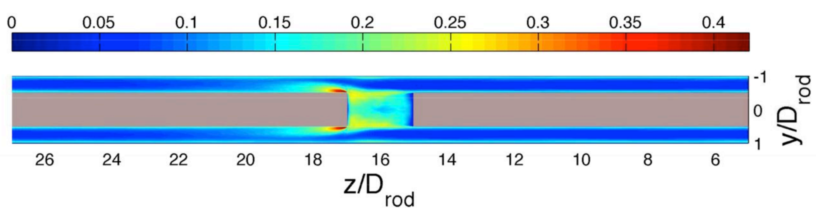
Concentric | Eccentric

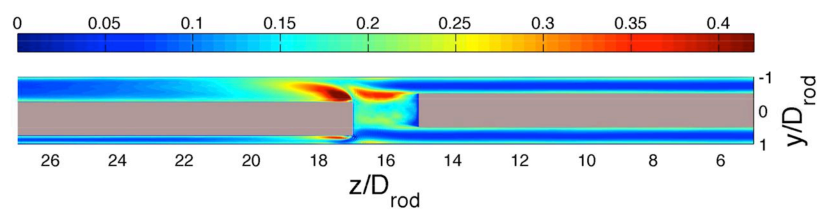
Mean Streamwise Velocity



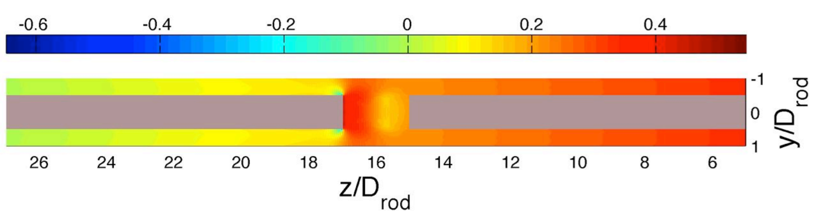


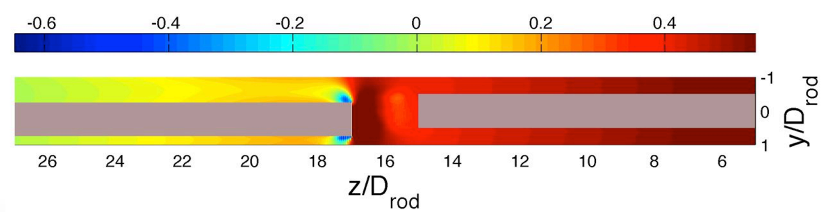
Streamwise Turbulence Intensity





Mean Pressure





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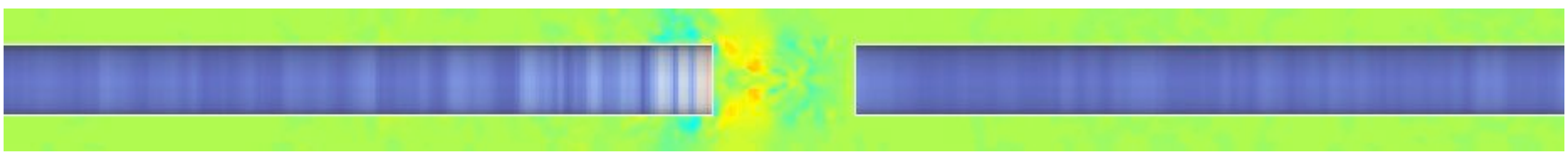
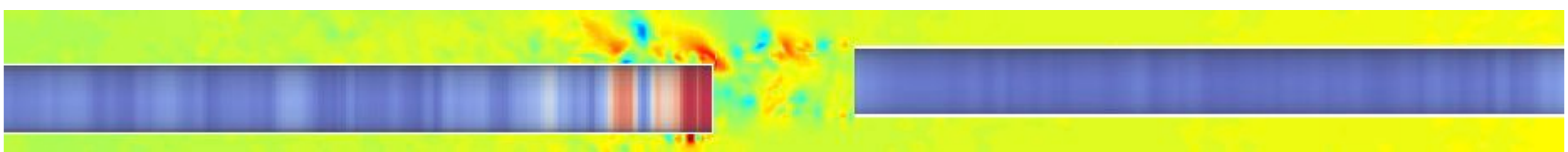
Eccentric Gap Case

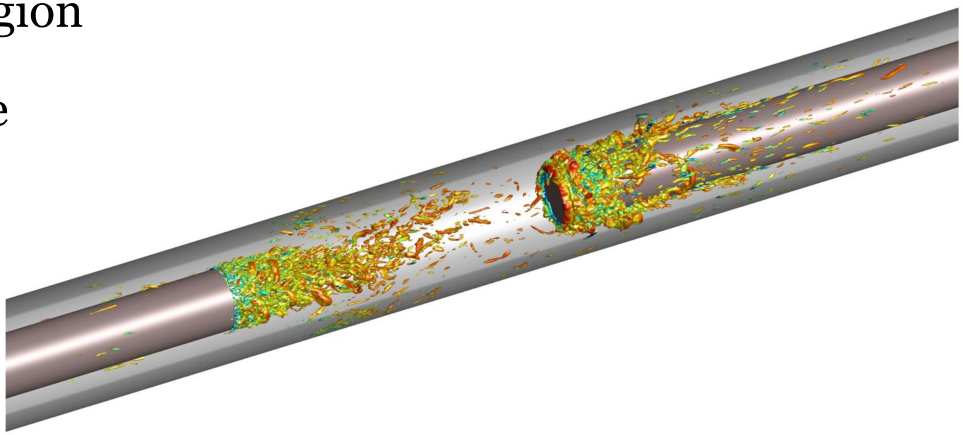
- Pressure fluctuations within the fluid domain and corresponding pressure force along the rods
  - Greater pressure force in eccentric configuration
  - Preliminary observations. Next step is to quantify and investigate the effect of the larger streamwise gap.





Conclusions

- Implemented *Precursor* and *Recycling* inlet methods in *Code_Saturne* v2.0
  - Both methods recover the periodic base flow within a distance of 2δ
- Investigated turbulent flow structure in a concentric annular configuration with 2 streamwise gap lengths. The geometry considered features:
  - Wall shear flow in annular region
  - Cavity flow in the 2D gap case
  - Wake flow in the 6D gap case
- Preliminary qualitative results with the addition of eccentricity to the downstream rod



Iso-surface of λ_2 for larger gap length

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The End

Thank you for listening

Any questions?

Or suggestions?

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