On the development of fibre orientation in jet-to-wire-impingement

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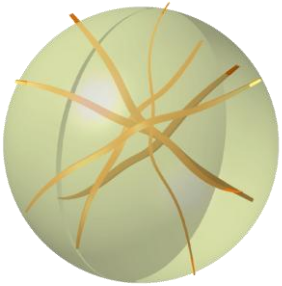
Outline

- Characters of fibre suspension flows in papermaking
    - ✓ Fibre orientation
- Modelling approach and model set-up for jet-to-wire impingement
- Results
- Summary

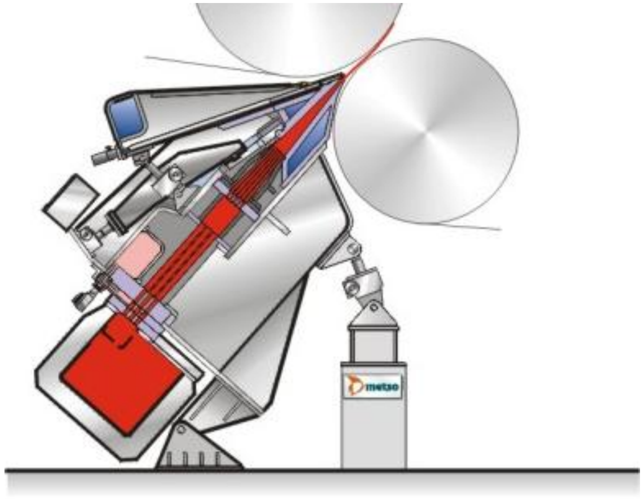
Fibre suspension flows in papermaking (1)

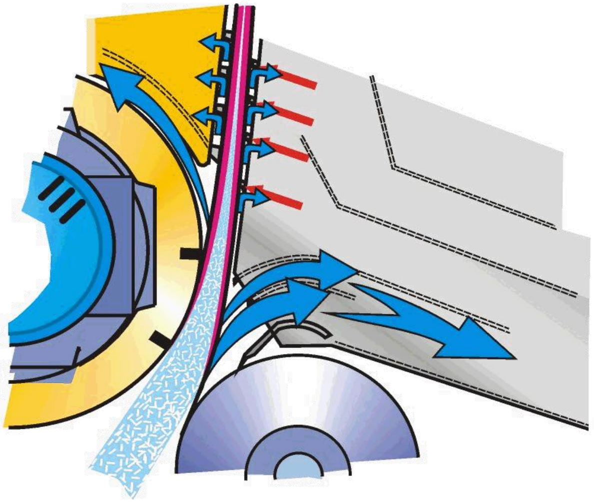
- Papermaking process contains complex flow phenomena
  - ✓ Multi-phase flow with fibre-fluid and fibre-fibre interactions
  - ✓ Turbulence
  - ✓ Sudden changes in shear strain rate, velocity and acceleration



- Fluid dynamics in the wet-end and in the forming section determines largely the properties of the paper
  - ✓ Headbox
  - ✓ Wire-section

Fibre suspension flows in papermaking (2)





By courtesy of Metso Paper.

Fibre orientation

- Misalignment of the fibre relative to the mean flow (or machine) direction

- Important factor in papermaking process
  - ✓ Affects dimensional stability, strength properties,...
  - ✓ Preferred orientation distribution depends on the purpose of the use of the paper

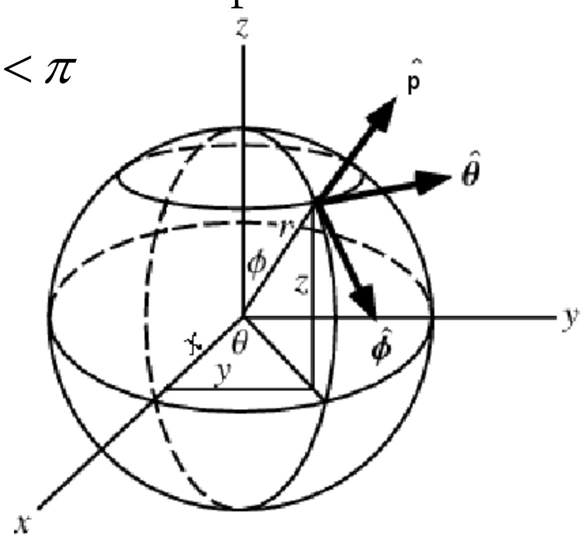
- Can be controlled with headbox fluid dynamics

Modelling approach (1)

- Fibre orientation determined with vector $\vec{p}$ using parametrisation

$$\vec{p} = \begin{pmatrix} \cos\theta\sin\phi \\ \sin\theta\sin\phi \\ \cos\phi \end{pmatrix}$$

where (ϕ, θ) polar and azimuthal angles determining the orientation on a unit sphere i.e. $0 < \theta < 2\pi$ and $0 < \phi < \pi$



- Due to the singularity at the poles $(\phi = 0, \phi = \pi)$ investigation of the orientation reduced in plane, i.e. $\phi = \pi / 2$

Modelling approach (2)

- Model based on assumption of probability distribution $\Psi(\mathbf{r},\mathbf{p},t)$
- Evolution of $\Psi(\mathbf{r},\mathbf{p},t)$ modelled with diffusion-convection equation

$$\frac{\partial \Psi}{\partial t} - D_t \Delta \Psi - D_r \Delta_{S^2} \Psi + \nabla \cdot (\vec{v}\Psi) + \nabla_{S^2} \cdot (\vec{w}\Psi) = 0,$$

where D_t, D_r = diffusion coefficients

$\vec{v}$ = fluid velocity

$\vec{w} = \omega \vec{p} + \lambda \varepsilon \vec{p} - \lambda < \vec{p}, \varepsilon \vec{p} > \vec{p}$ = rotational velocity of the fibre

with

$$\varepsilon = \frac{1}{2}(\nabla \vec{v} + (\nabla \vec{v})^T)$$ = shear strain rate

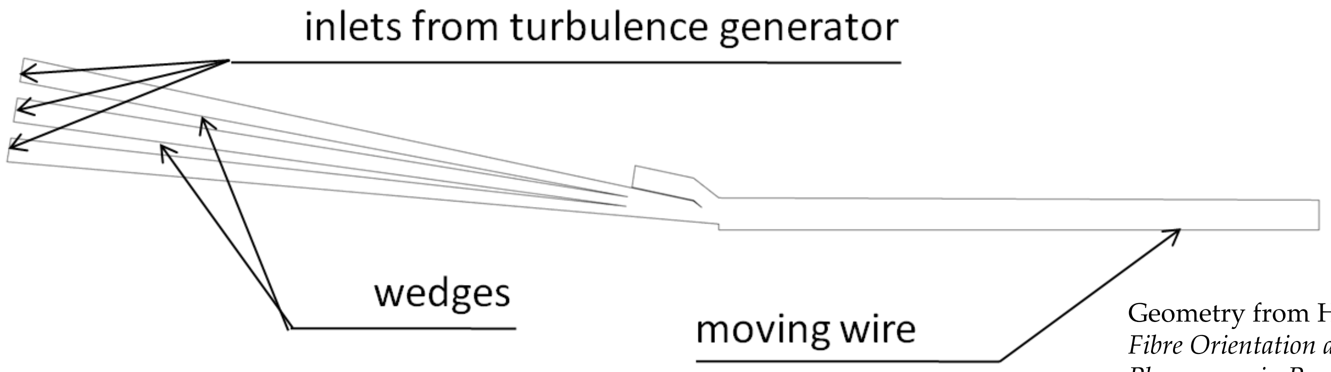
$$\omega = \frac{1}{2}(\nabla \vec{v} - (\nabla \vec{v})^T)$$ = vorticity

Modelling approach (3)

- Planar reduction and differential geometry

$$\vec{w} = w_1 \partial_\theta + w_2 \partial_\phi$$
$$w_1 = -\sin(2\theta)\varepsilon_{11} + \cos(2\theta)\varepsilon_{12} - \omega_{12}$$
$$w_2 = 0$$

- FEM solver with velocity profiles imported from ANSYS CFX 12.1



Geometry from Hämäläinen, T. *Modelling of Fibre Orientation and Fibre Flocculation Phenomena in Paper Sheet Forming, PhD thesis,2008*

Modelling approach (4)

- Fixed jet velocity ~28,7 m/s
  - ✓ 3 different J/W ratios
    - J/W=0.9 -> wire velocity ~31,9 m/s
    - J/W=1.0 -> wire velocity ~28,7 m/s
    - J/W=1.1 -> wire velocity 26,1 m/s

- Sink term at the wire to consider the water removal defined as

$$\frac{\dot{q}}{A} = \sqrt{\frac{2p\rho_c}{R_w}}$$

Flow rate ($\dot{q}$)

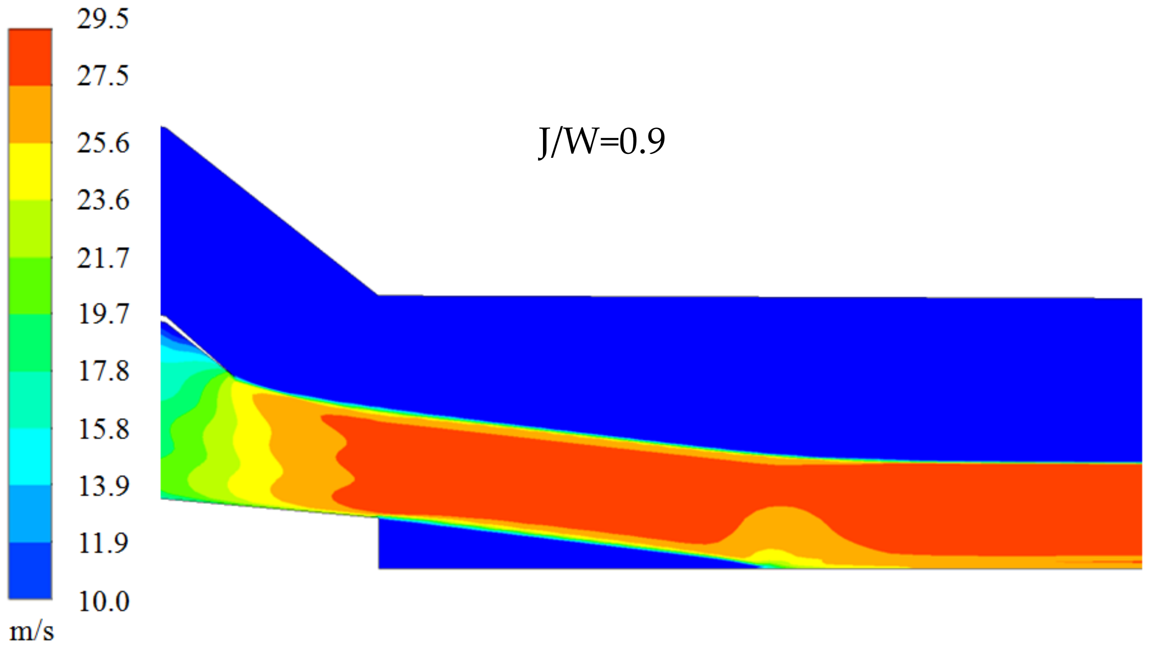
Surface area (A)

Pressure on top of the wire (p)

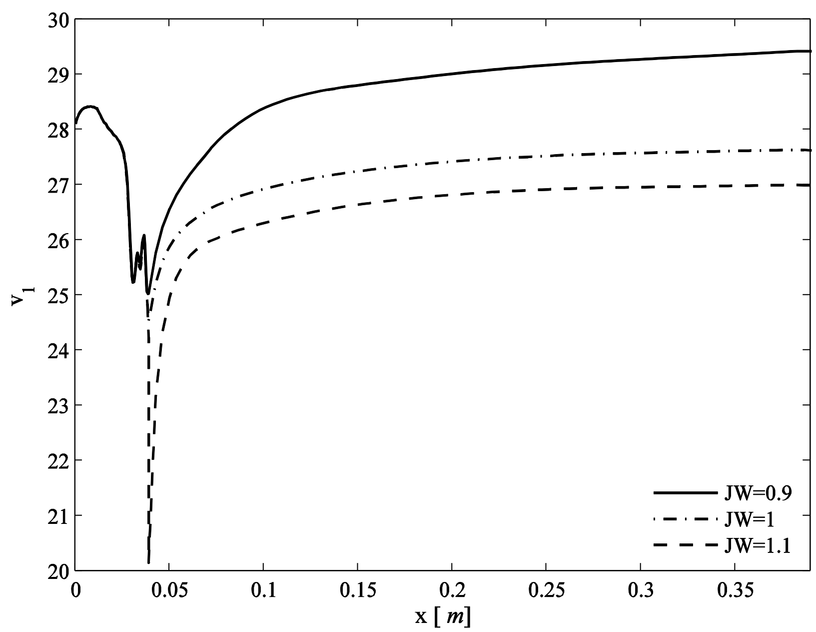
Water density (ρ_c)

Coefficient for fabric resistance (R_w)

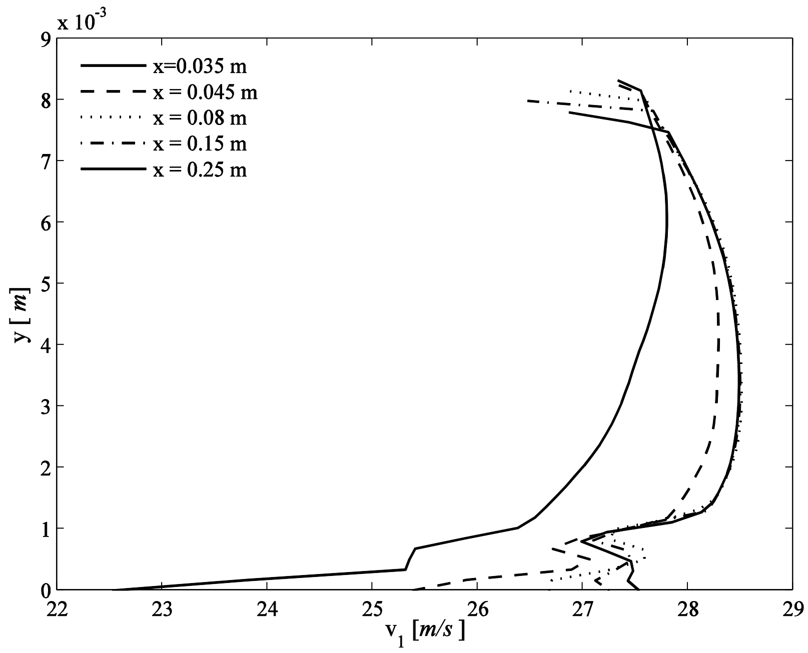
Results: Flow field (1)



Results: Flow field (2)

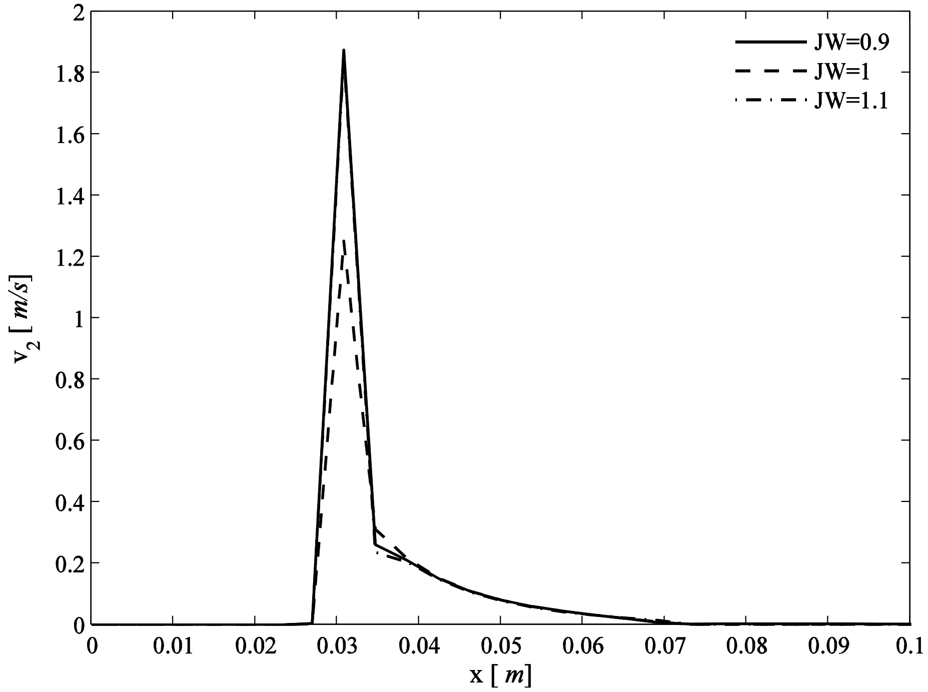


Flow velocity in machine direction



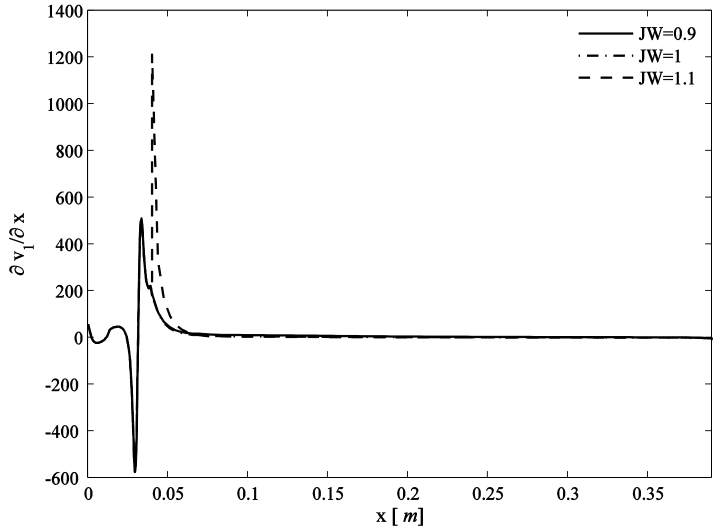
Flow velocity across the jet

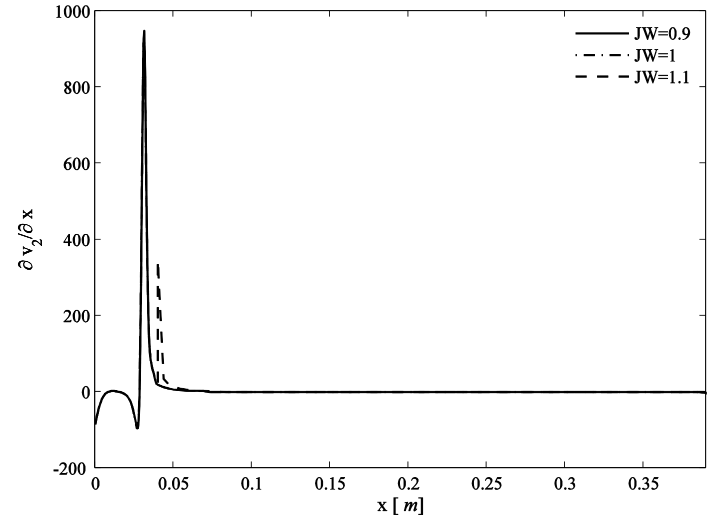
Results: Flow field (3)

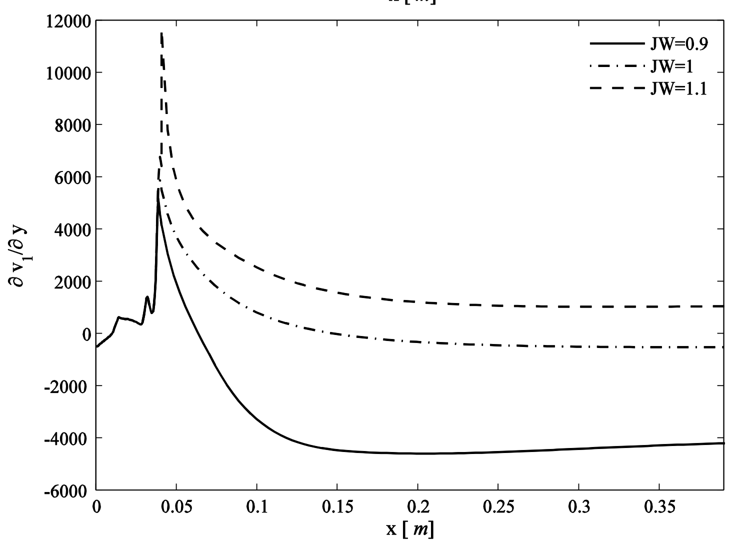


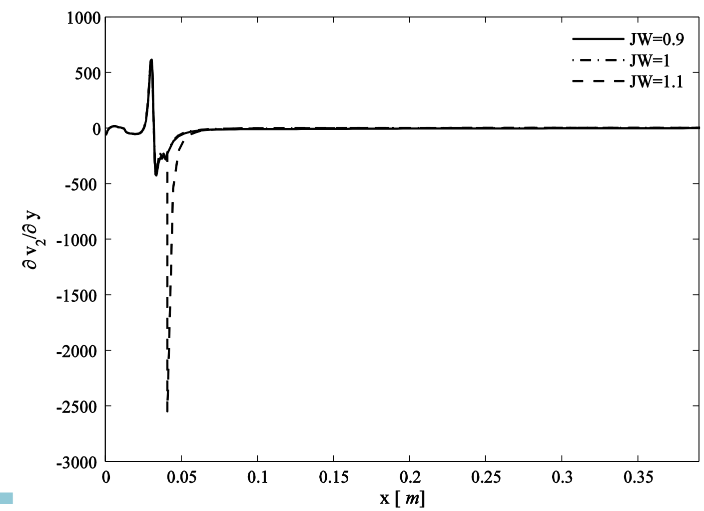
Velocity perpendicular to the mean flow

Results: Flow field (4)

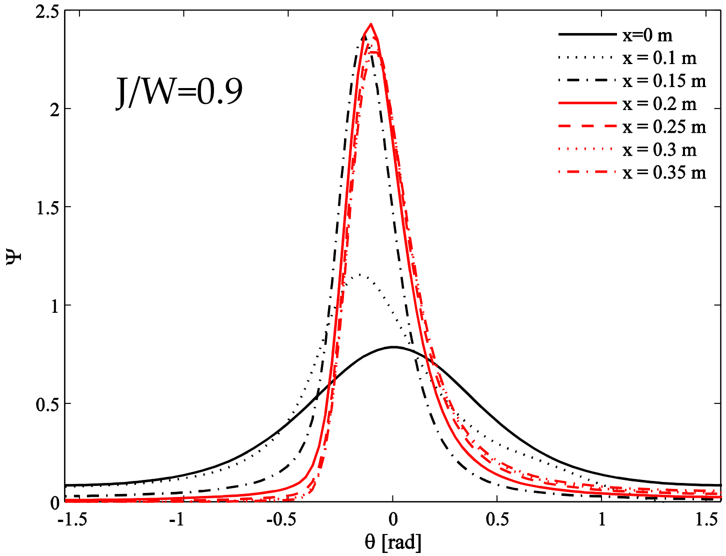


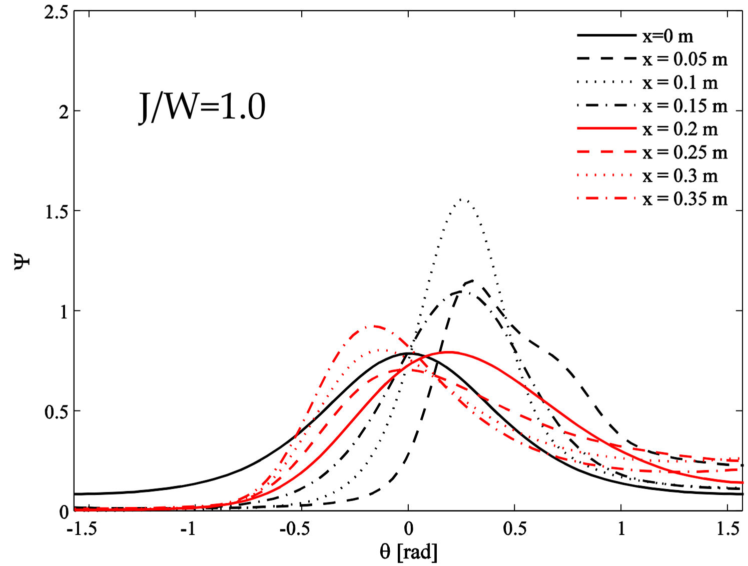


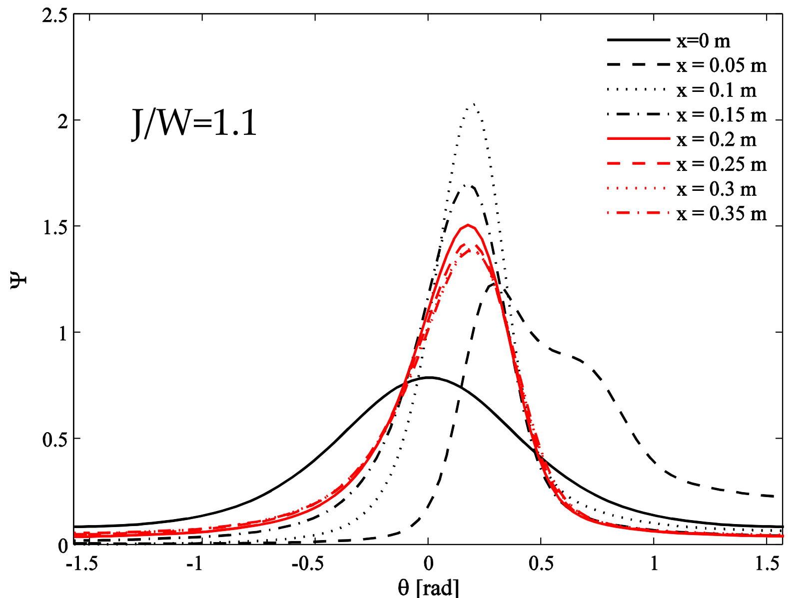




Results: Fibre orientation distribution







Summary

- Fibre orientation probability at the forming section
  - ✓ Probability distribution approach with diffusion-convection equation and rotation of the fibre determined from the flow field
    - Planar reduction due to the singularity
- Jet-to-wire speed difference affect the orientation distribution
  - ✓ Strongest orientation with biggest wire velocity

Thank you for your attention!

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