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Combined PIV and fibre orientation measurements on the KTH water-table

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Outline of the talk

- Motivation
- The aspects of the presence of fiber in turbulent flows
- Objectives
- Experimental Facility and Experiment Conditions
- Data processing and analysis
- Results

• Motivation

✓ The knowledge of the behavior of Fiber-laden turbulent flows covers wide range of applications:

- Paper manufacturing
- Carbon nanotubes
- Fluid and gas transport
- Air and water pollution
- …

- **The important aspects of the presence of fiber in turbulent flows**

✓ Modulation of carrier phase turbulence due to the presence of fibers

✓ Preferential concentration of fibers

✓ Effect of turbulence on the coupling between the dispersed and carrier phases

✓ Orientation of fibers in flow

• Objectives

- ✓ To find new approach to measure simultaneously velocity of main flow and orientation of fiber.
- ✓ To provide information on local structures of flow, fiber positions and fiber orientations.
- ✓ Preferably measuring of the mean velocity and statistics of the turbulent velocity fluctuations in order to perceive better phenomenon of turbulent dispersed multiphase flows.

• Experimental Facility & Experiment Conditions

✓ Experimental set-up

-Experiments were conducted on the water table at Fluid Mechanics Lab, KTH.

-A dilute suspension of cellulose acetate fibres into tap water.

-The film of suspension flowed down, dived by gravity, on the slightly inclined water table :

-Thickness of film: h≈ 8 mm

-Angle of slope: α≈0.14 deg.

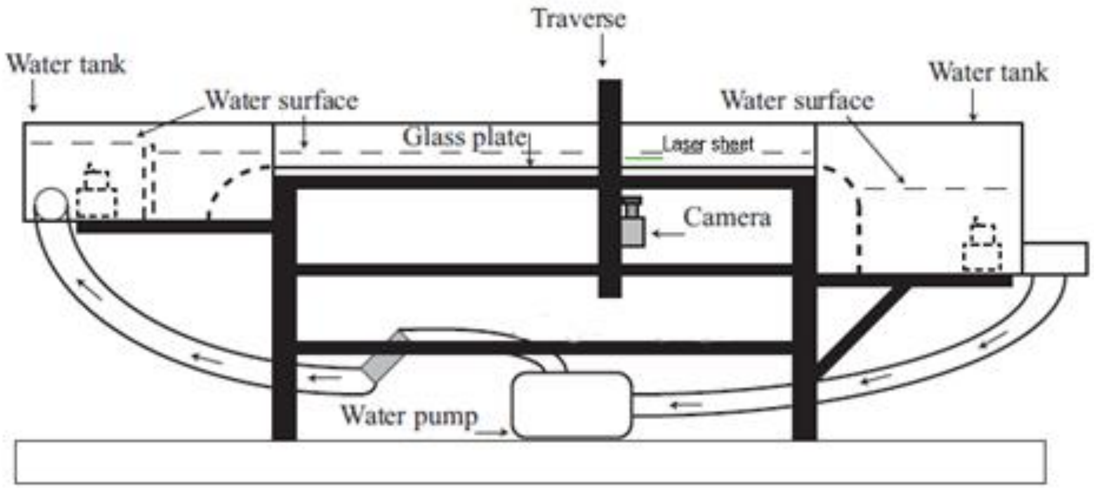

FIGURE A.1. Schematic of the experimental setup. From Fjellgren (2007).

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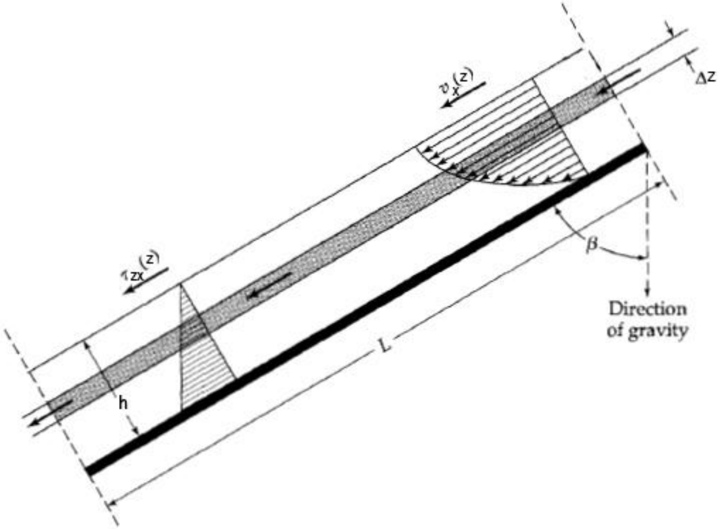
- This is a good experimental model of one half of channel flows often used in direct numerical simulation studies.

$$\tau = \rho g \, sin\alpha \, (h - y)$$

$$\tau_w = \rho g h \, sin\alpha$$

$$Re_\tau = \frac{h\sqrt{gh \, sin\alpha}}{\nu}$$



- The friction Reynolds number (based on the layer thickness, which corresponds to half the channel width in a channel flow) is $Re_\tau \approx 100$

✓ Experiment Conditions:

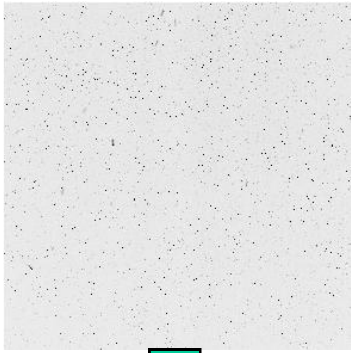
-Cellulose acetate fibres with density of 1300 kg/m3 and diameter of 70 µm.

-three different types of fibers in length: 0.5 mm (r_p≈7), 1mm (r_p≈14) & 2 mm (r_p≈28)

- Experiments was conducted in three different distances from the bottom wall of water table: 1mm, 3mm & 5mm.

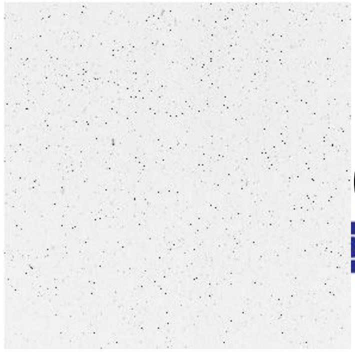
Fiber specification		y=1 (mm)	y=3 (mm)	y=5 (mm)
0.5 (mm)	r_p=7	√	√	√
1 (mm)	r_p=14	√	√	√
2 (mm)	r_p=28	√	√	√

- **Image processing and analysis**



spatial median filtering proposed by Kiger & Pan (2000)

steerabe filter developed by A.Carlsson, K. Håkansson, M. Kvick, F.Lundell & D. Soderberg



PIV analysis performed on tracer images

✓ Median Filter:

-The median filter is a nonlinear signal processing technique in order to reduce random noise and periodic interference patterns.

-In PIV image processing, Median filtering considers tracers as noise and removes noise which consists of strong spikelike components (tracers), while preserving sharp edges of objects (e.g. Image of large particles or fibers).

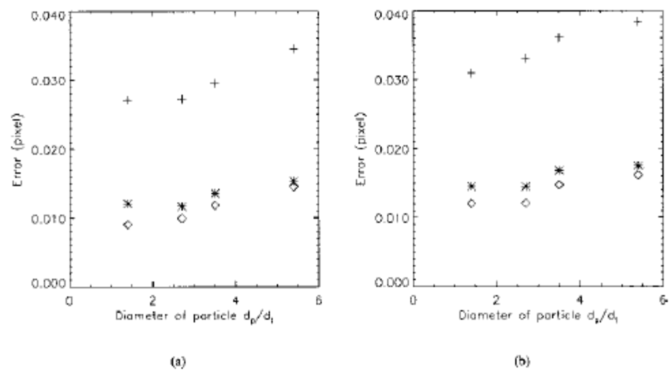


Fig. 7 Average absolute displacement error of carrier phase. (*a*) Spanwise direction. (*b*) Streamwise direction. +, filter width f/d_t=1.3; ∗, filter width f/d_t=2.4; ◇, filter width f/d_t=2.9. (kiger & Pan, 2000)

-In our case, a Median filter with the filter width, f, of 9 pixels was applied.

✓ Steerable Filters:

- The steerable filters are a class of filters in which a filter of arbitrary orientation is obtained from a linear combination of basis filters, introduced first by Freeman & Adelson (1991).

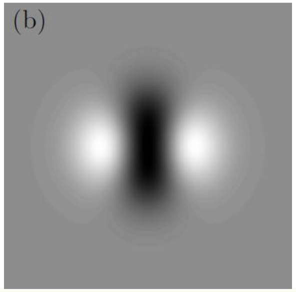
-A filter in class of steerable filters for ridge detection was proposed by Jacob & Unser (2004) and was developed by Carlsson, Lundell & S¨oderberg (2007).

-The ability of this filter in order to determine the orientation of fibres in digital images obtained from some optical diagnostic techniques in fluid dynamics have been found to be excellent with acceptable accuracy.

- $I(m,n) = f(m,n) * h(x,y)$

$$h(x,y) = \sum_{\kappa=1}^{M} \sum_{\lambda=0}^{\kappa} \alpha(\kappa,\lambda) \frac{\partial^{\kappa-\lambda}}{\partial x^{\kappa-\lambda}} \frac{\partial^{\lambda}}{\partial y^{\lambda}} g(x,y)$$

$$g(x,y) = e^{-(x^2+y^2)}$$

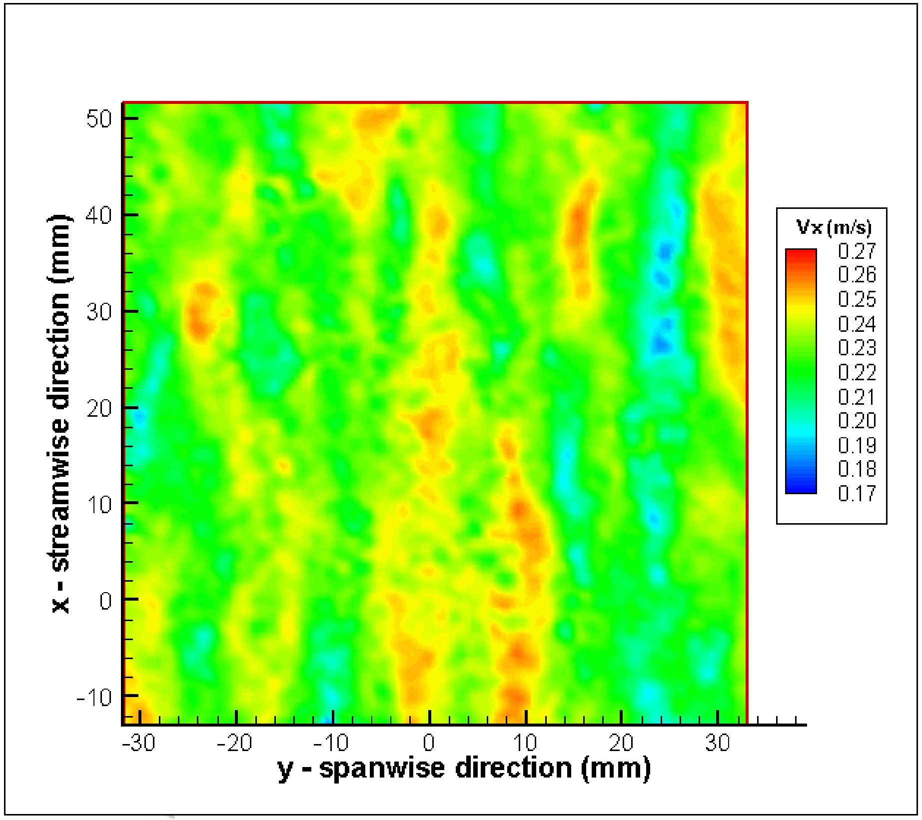


• Results

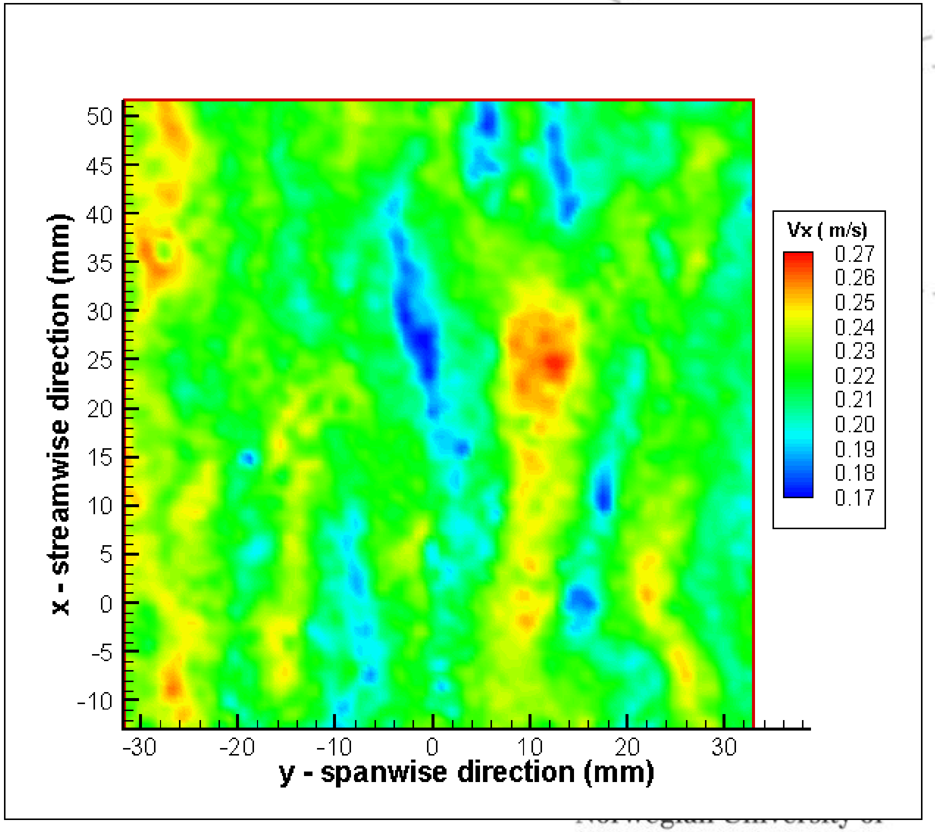
✓ Behaviour of 1 mm fibers:

✓ Contour of streamwise velocity (V_x) at z=3 mm:

Coherent structures in turbulence of flow

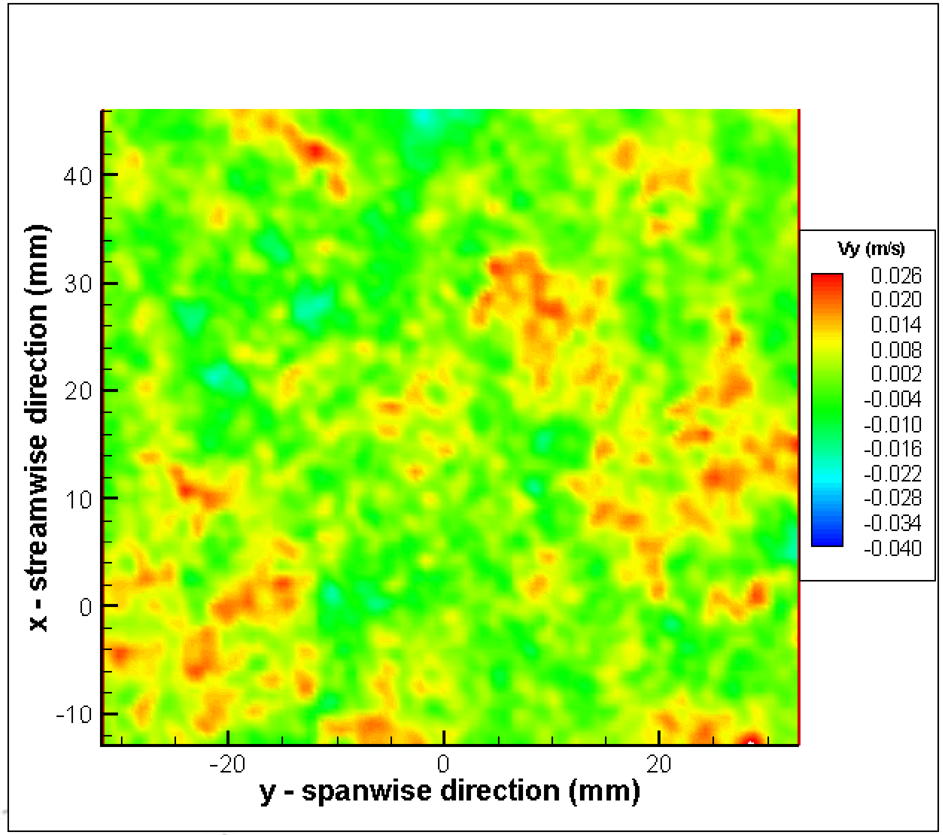


Coherent structures in turbulence of suspension

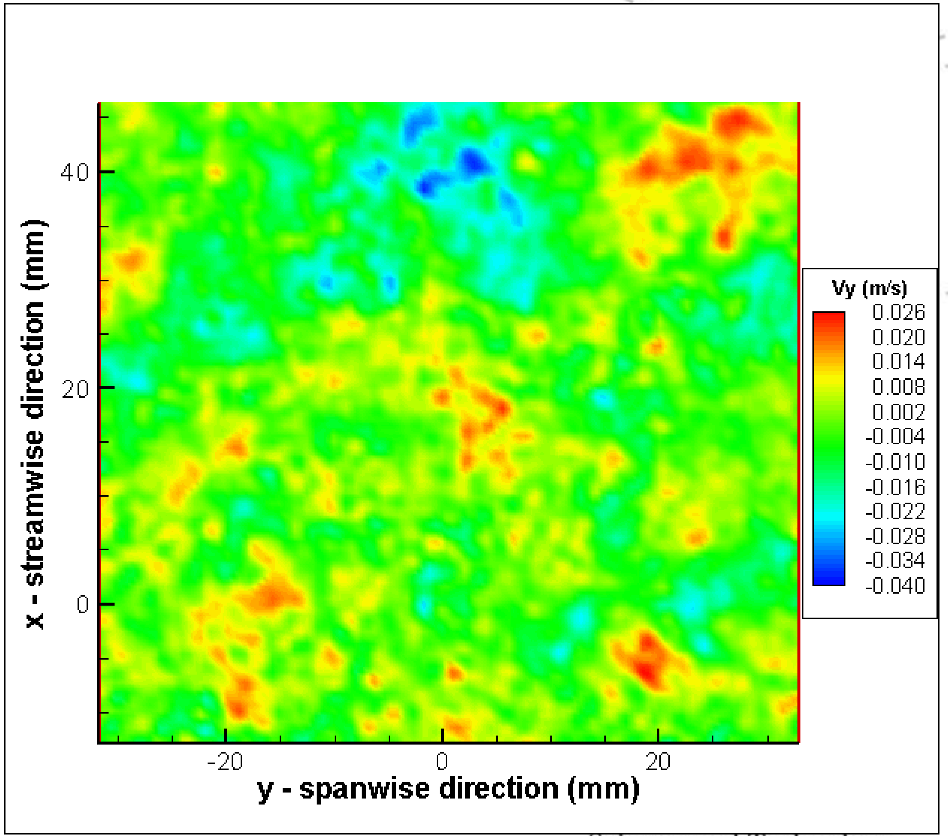


✓ Contour of spanwise velocity (V_y) at z=3 mm:

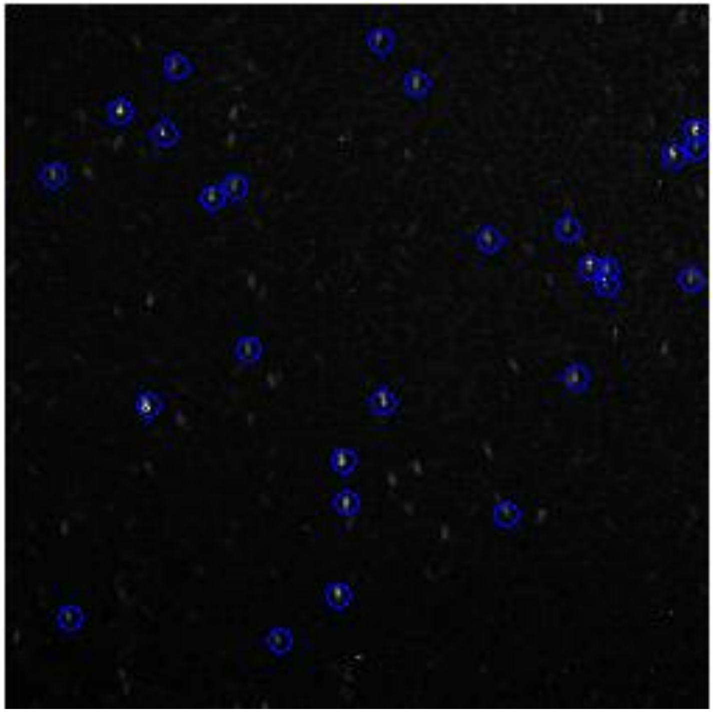
Coherent structures in turbulence of flow



Coherent structures in turbulence of suspension



- ✓ Fiber detecting with steerable filter:



Thanks for your Attention