Fibre orientation in wall turbulent flow

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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
- Image processing and analysis
- Brief 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 was used, Φ_v.<10^{-5}

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

-Thickness of film: h≈ 12±0.1 mm

-Angle of slope: α≈0.076 deg.

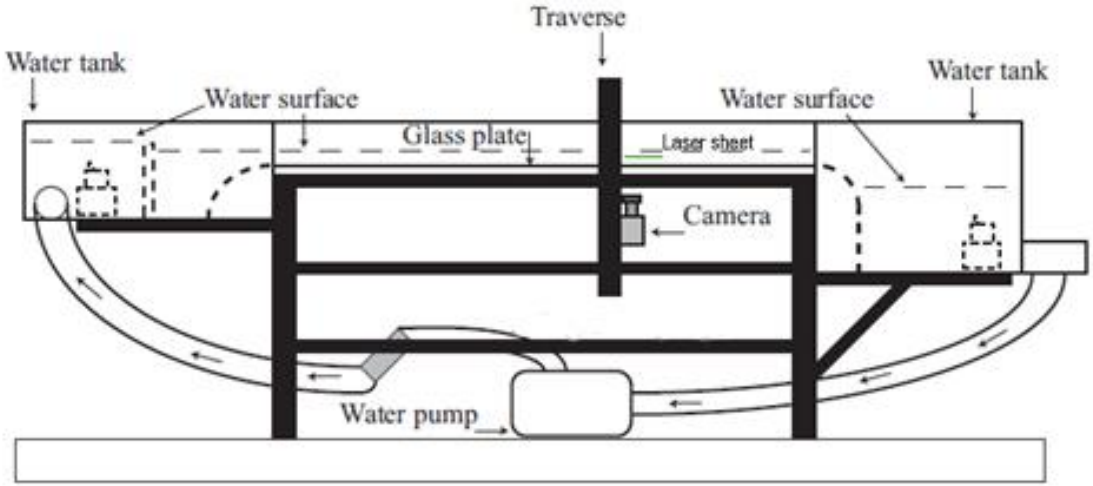

FIGURE A.1. Schematic of the experimental setup. From Fjellgren (2007).

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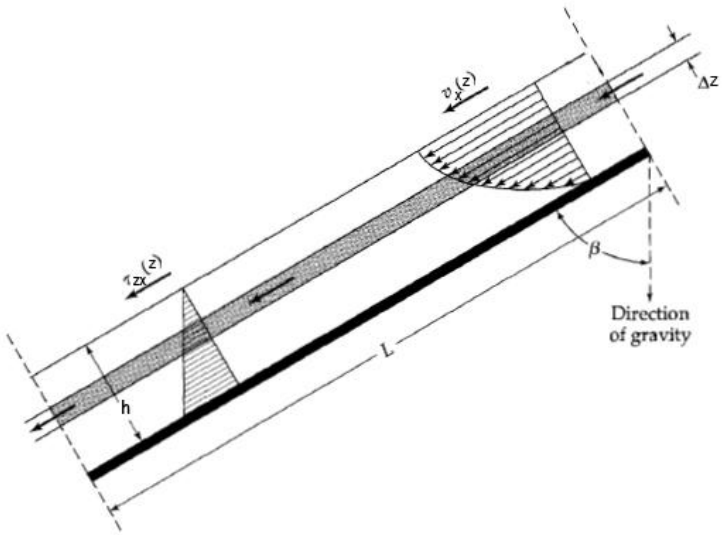
- This is an experimental model of one half of channel flows often used in direct numerical simulation (DNS) studies.

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

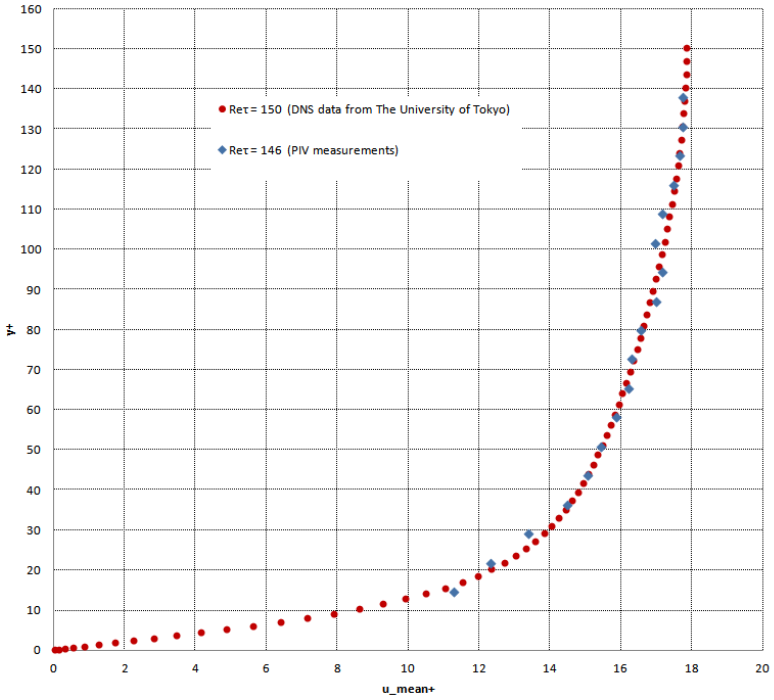
$$\tau_w = \rho g h \, sin\alpha$$

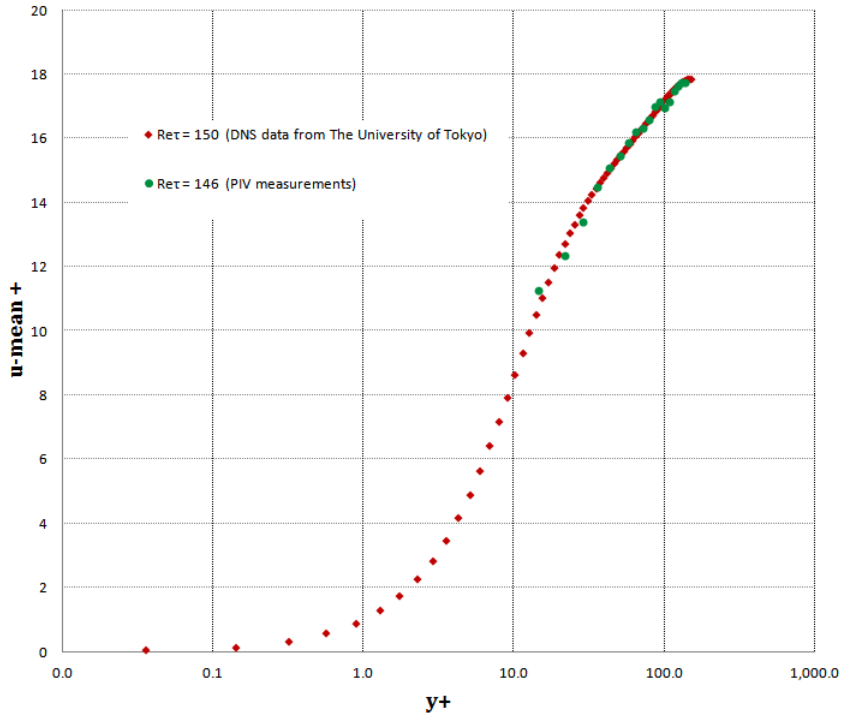
$$Re_\tau = \frac{h\sqrt{gh \, sin\alpha}}{\nu}$$



- The friction Reynolds number (based on the film thickness, which corresponds to half channel width in the channel flow) is **$Re_\tau \approx 150$**.

✓ PIV Measurements on The Water Table





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✓ 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 (z^+=15), 3mm (z^+=45) & 5mm (z^+=75)

	Fiber specification		z^+=15	z^+=45	z^+=75
Case 1	0.5 (mm)	r_p=7	√	√	√
Case 2	1 (mm)	r_p=14	√	√	√
Case 3	2 (mm)	r_p=28	√	√	√

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- ✓ Behaviour of 1 mm fibers in the film of suspension:

- **Image processing**
  - ✓ 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).

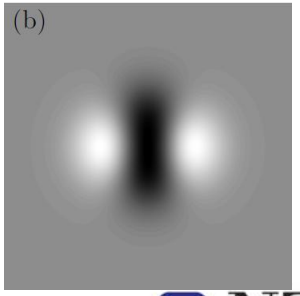
-A filter in class of steerable filters for ridge detection was proposed by Jacob & Unser (2004) and was developed by Carlsson, Lundell & S¨oderberg (2007).

-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.

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

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

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



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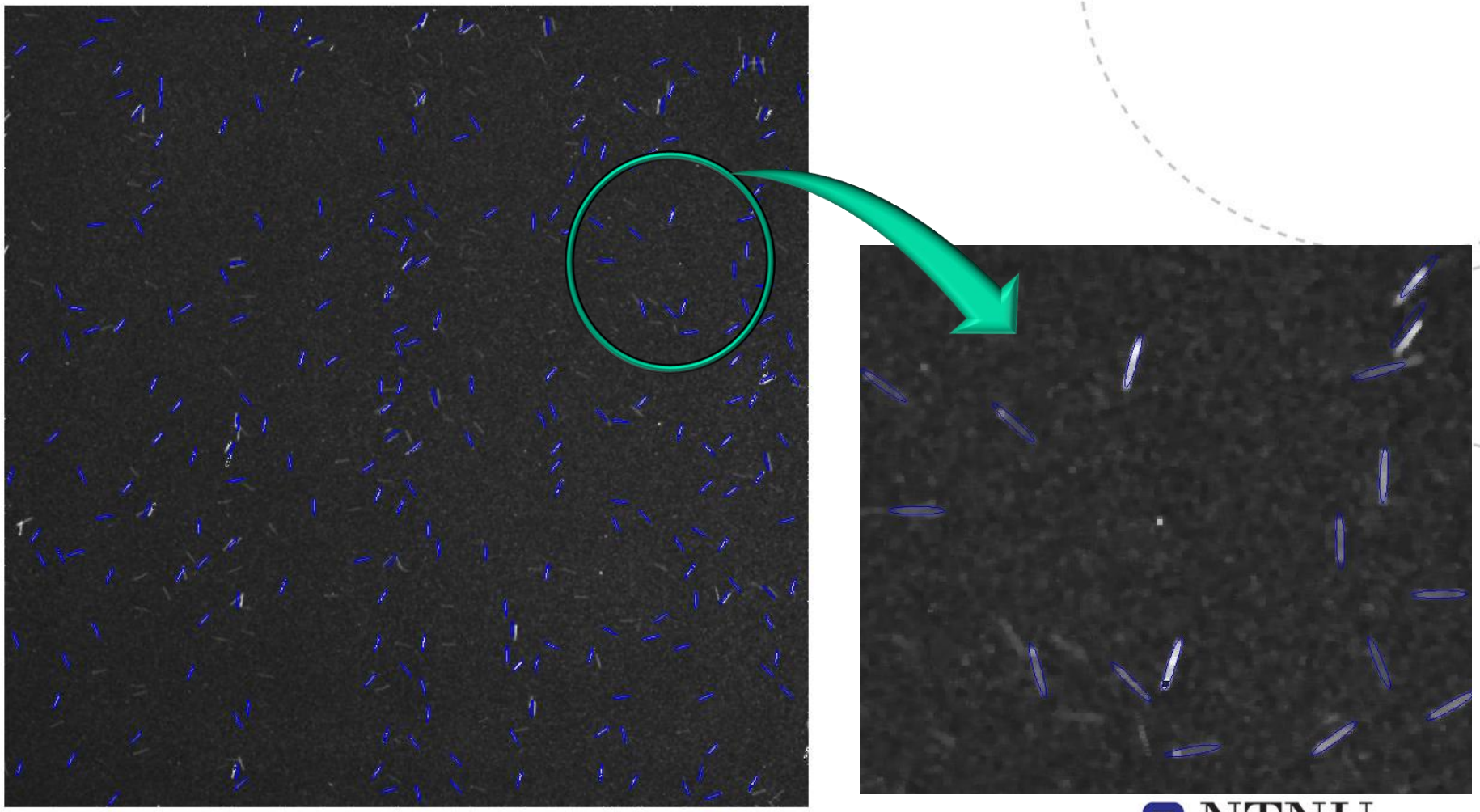
- ✓ The fibers detected by Steerable filter:



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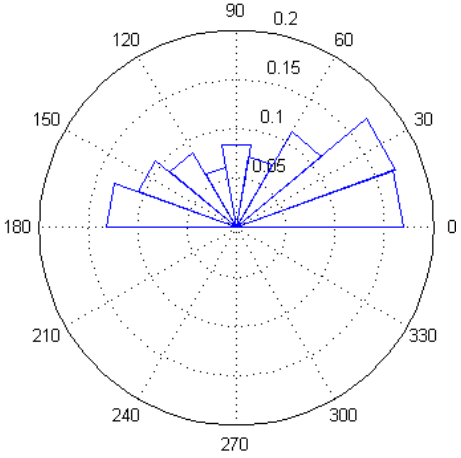
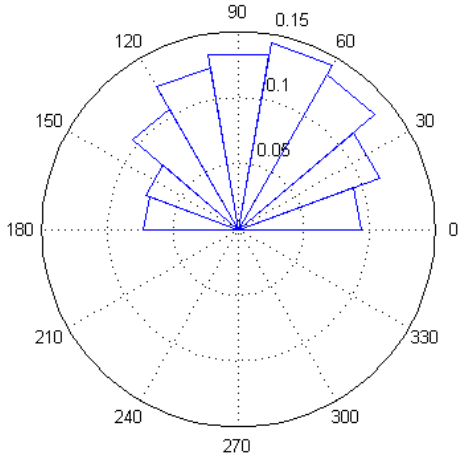
• Results

✓ The histogram of fibres orientation distribution

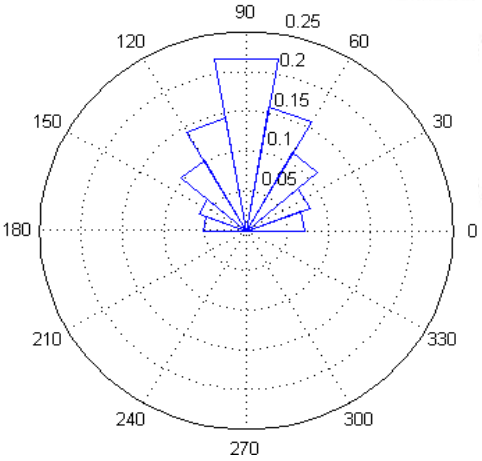
Fibres of r_p =7 (0.5 mm fibres):



Fibres of r_p =14 (1 mm fibres):



Fibres of r_p =28 (2 mm fibres):



(The direction of mean flow in angle of 90)

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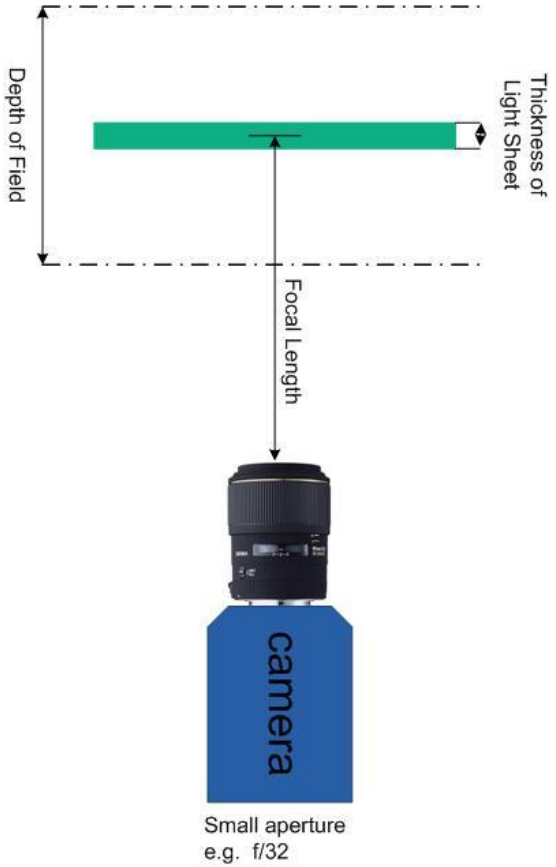
•Detecting of fibers in certain level:

- ✓ PIV and Optics Set-up:



$$d_\tau \cong \sqrt{M_0^2 d_p^2 + d_s^2}$$

$$d_s \cong 2.44\left(1+M_0\right) f^{\#} \lambda$$

$$\delta z \cong 4\left(1+\frac{1}{M_0}\right)^2 f^{\#2} \lambda$$

$$M_0 = z_0 / Z_0$$

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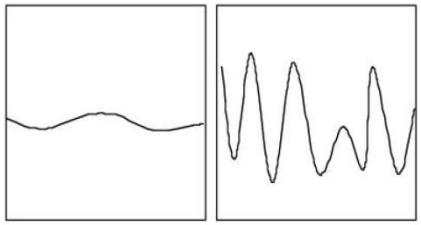
✓ Method of Detecting Blurry/Sharp Images

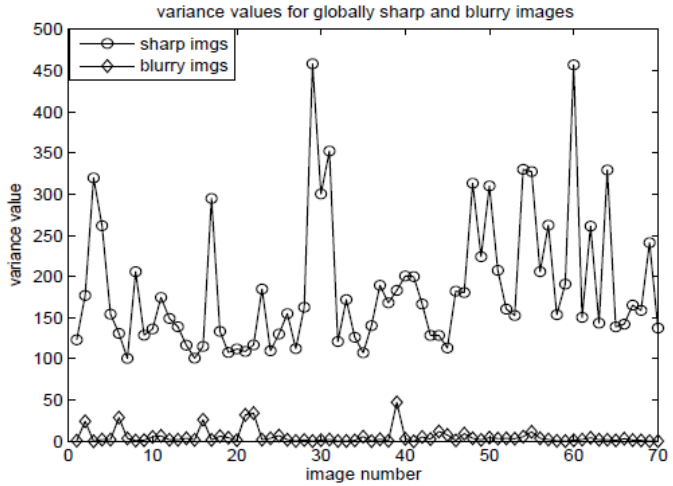
- Typical causes of blurriness include: Imperfect focusing (out of focus), camera jitter, motion of object, limited contrast, inappropriate exposure, … .

- The Conceptual illustration of blurry (left) & sharp (right) images:



- Batten et al. found variance measure is better in terms of computing time and immunity to noise. ["Sharpness search algorithms for automatic focusing in the scanning electron microscope", Proceedings of SCANNING, 2001]

$$\sigma^2 = \frac{1}{MN}\sum_{x=1}^{M}\sum_{y=1}^{N}[u(x,y) - \bar{u}]^2$$



Elena Tsomko et al.,"Efficient Method of Detecting Blurry Images", JOURNAL OF UBIQUITOUS CONVERGENCE TECHNOLOGY, VOL. 2, NO. 1, MAY 2008

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Thanks for your Attention