The effect of channel contraction profile and turbulence on fiber orientation

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Outline

Motivation

Channels

Experimental setup

Flow statistics and fiber orientation

PIV results

- Velocity profiles
- Rate of strain
- Turbulence

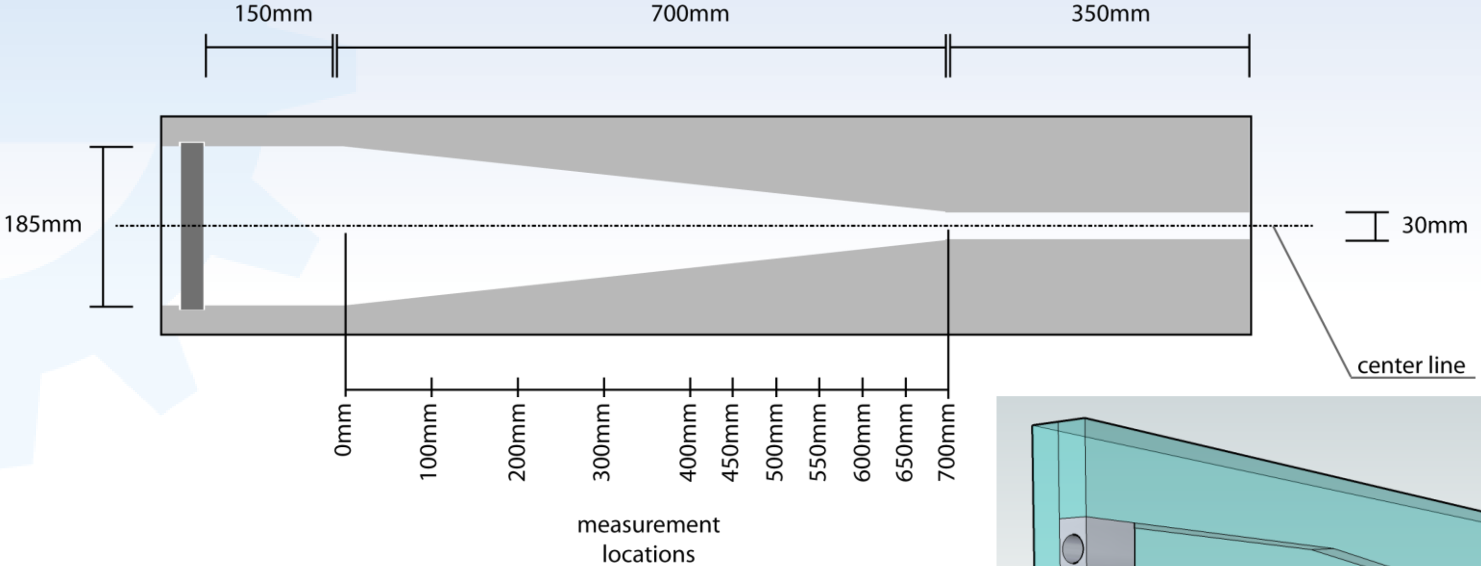
Fiber orientation

- Measurement method
- Orientation anisotropy
- Results & discussion

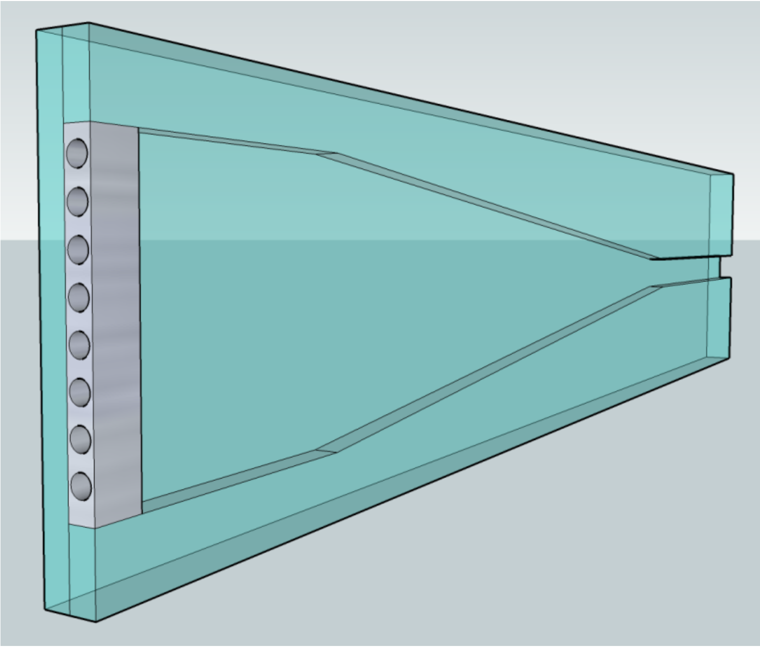
Motivation

- Fiber orientation is one of the key quality factors of paper products
  - Trend: thinner paper with less fibers, varying fiber material
    → Maintain or even improve strength properties, runnability and dimensional stability of paper
    → Optimize fiber orientation
    → Experiments, modelling, simulations
- Lack of experimental data for different fiber types, studied in the same, controlled flow conditions
  - Models developed mostly for rigid and straigth fibers
  - How to define the orientation angle of curly or crossing fibers?
- Fiber types in this study:
  - Real wood fibers: pine and eucalyptus
- Flow statistics & orientation evolution can be reflected

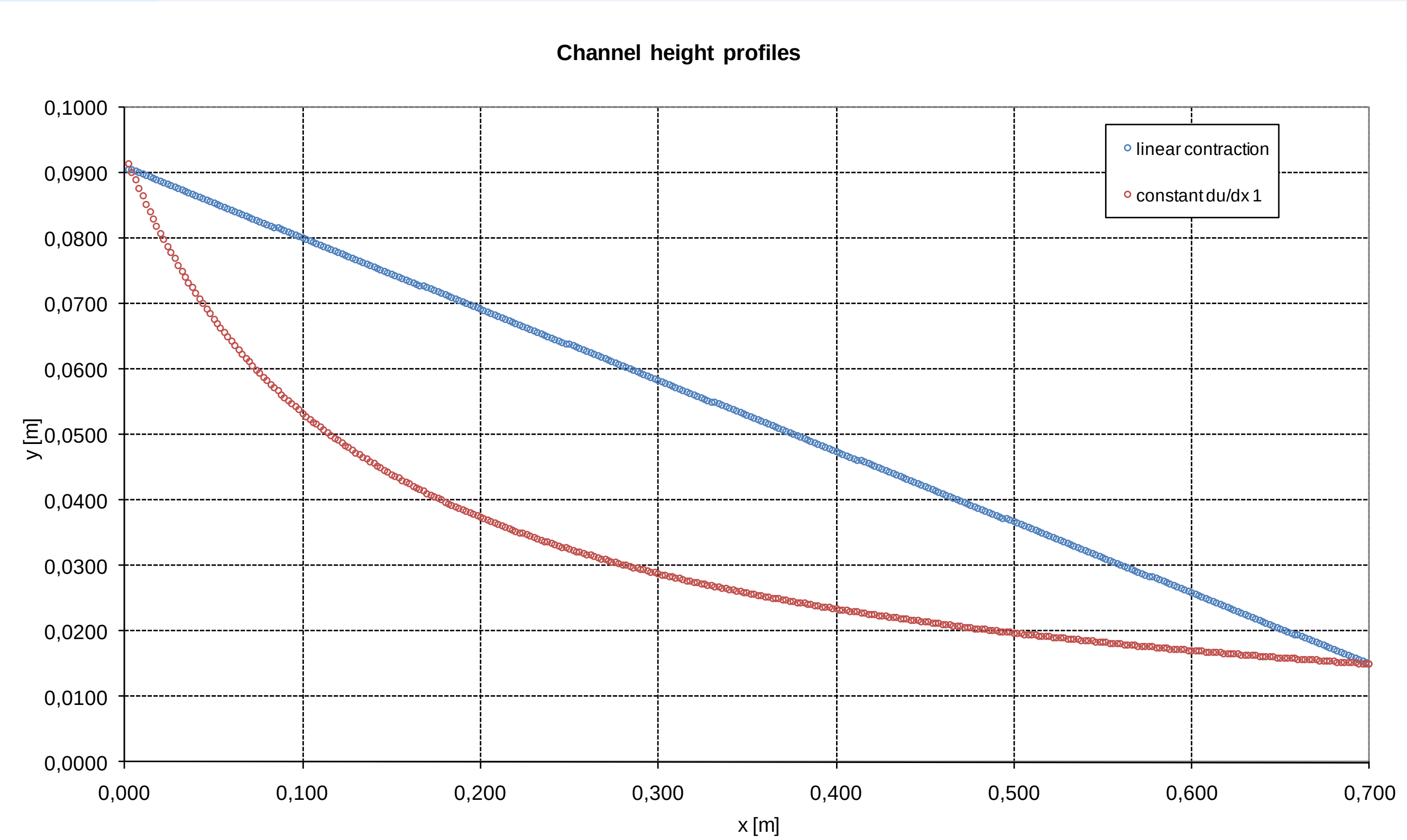
Channels



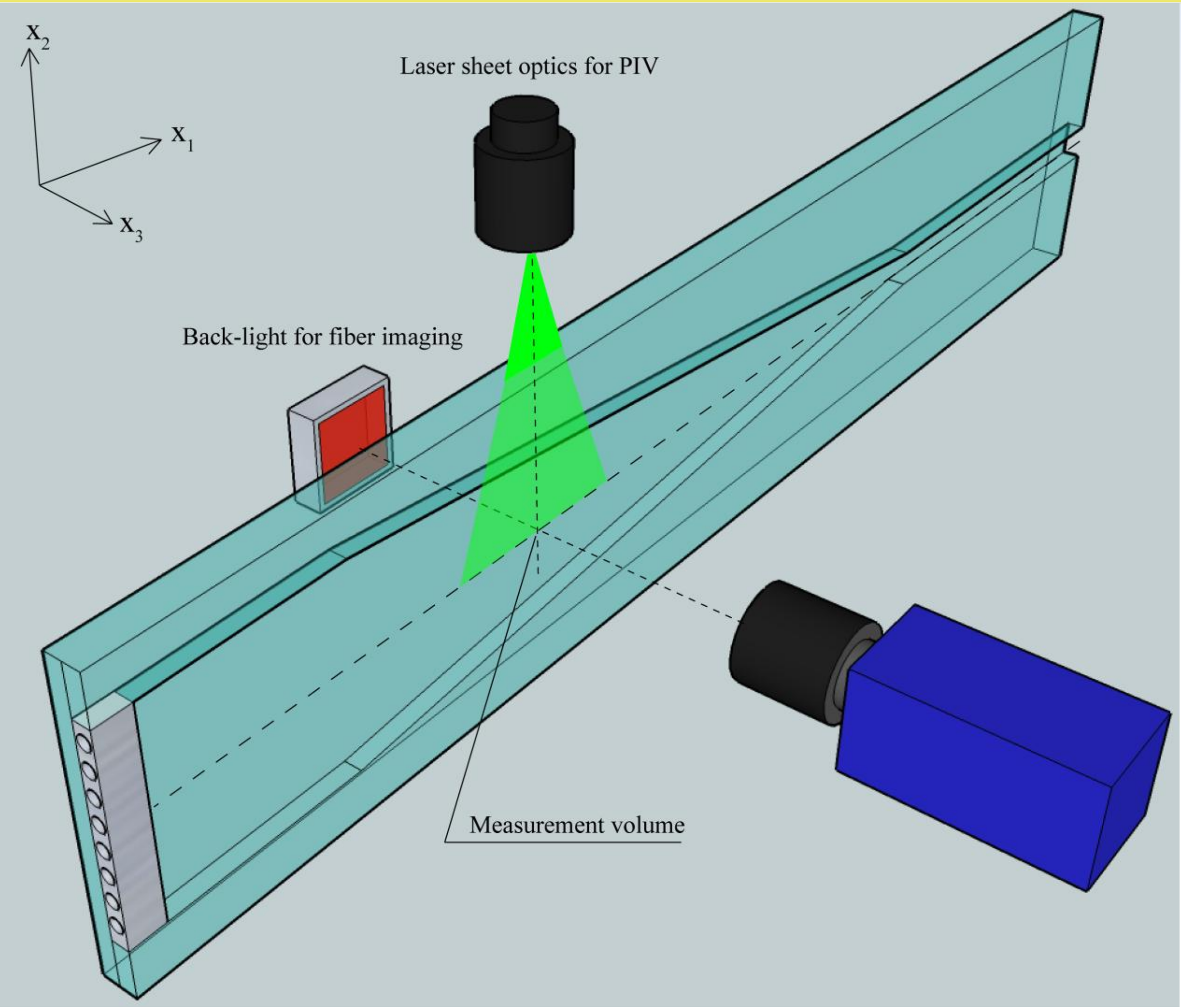
- Channel width 15 mm
- Contraction ratio1:6 in both channels
- ø 12 mm in turbulence generator
- Closed loop, flow rates 2.25 l/s and 4.0 l/s



Channel profiles



Measurement setup



PIV results

Local flow statistics :

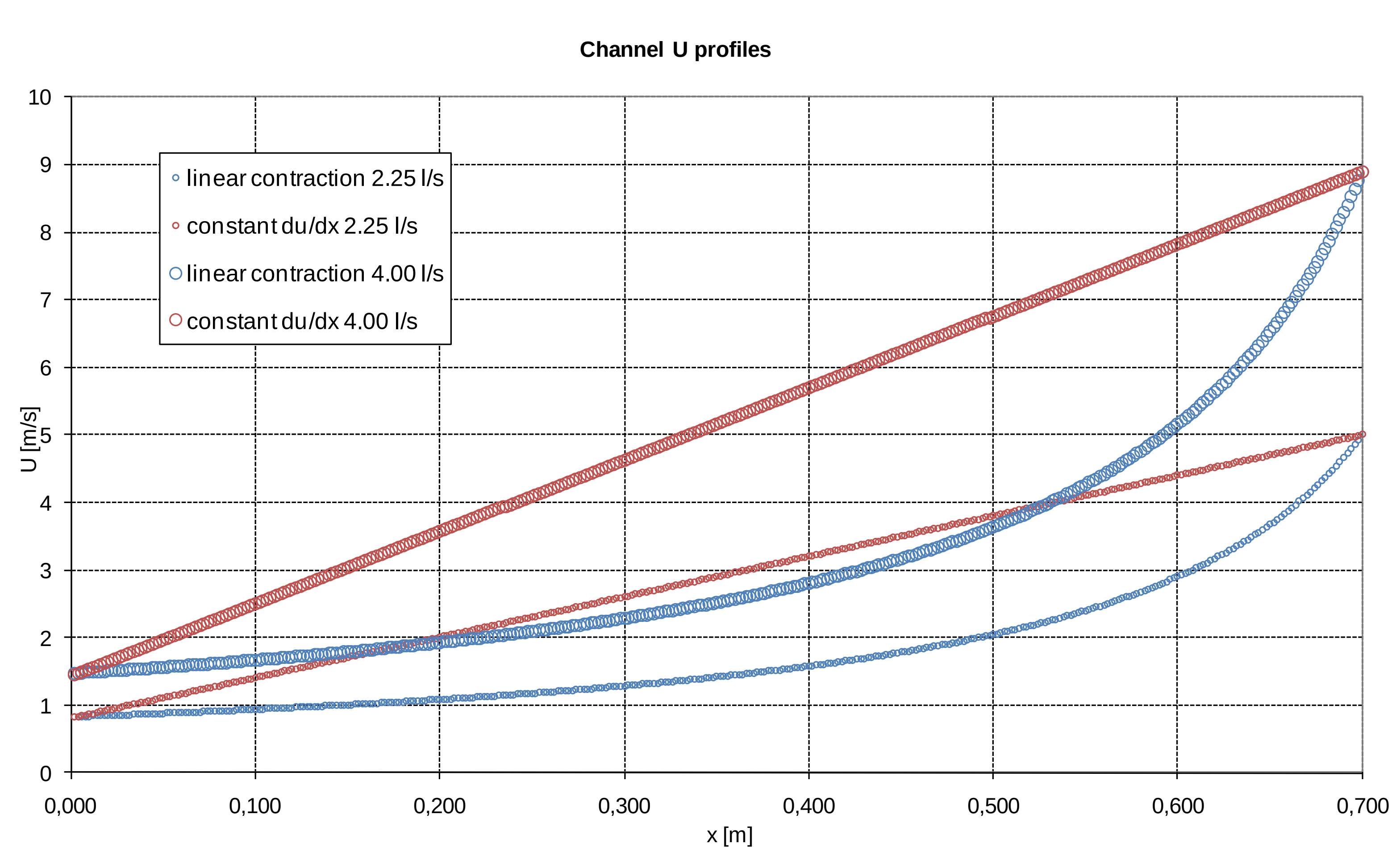
- Mean streamwise velocity U_1
- Streamwise (normal) rate of strain
- Turbulence intensity

Profiles as a function of measurement location (x_1) and local contraction ratio C, defined as

$$C = \frac{U_1}{U_{1,0}}$$

Comparison to corresponding measurements made in wider channel (Parsheh et al. 2005)

MD – velocity profiles



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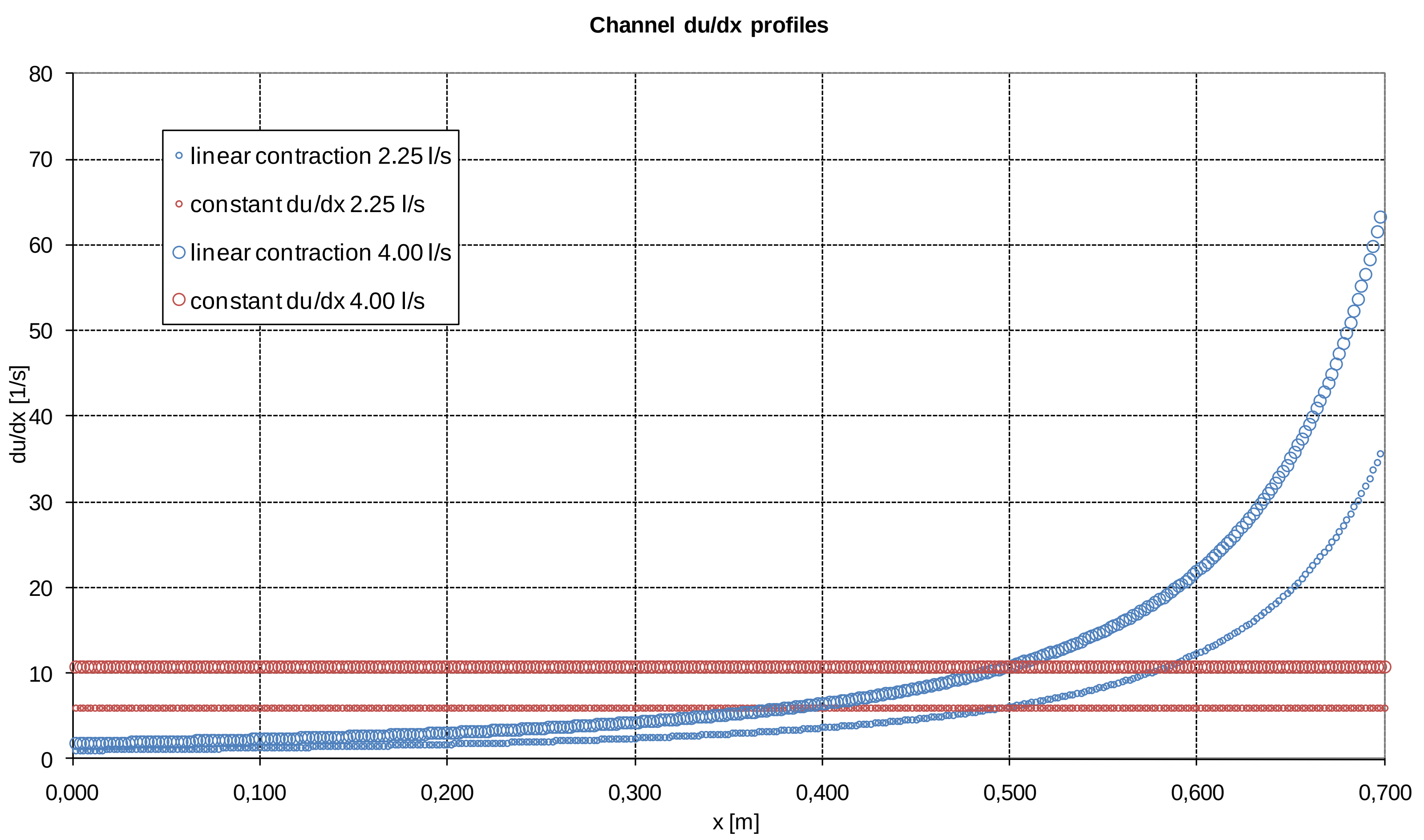
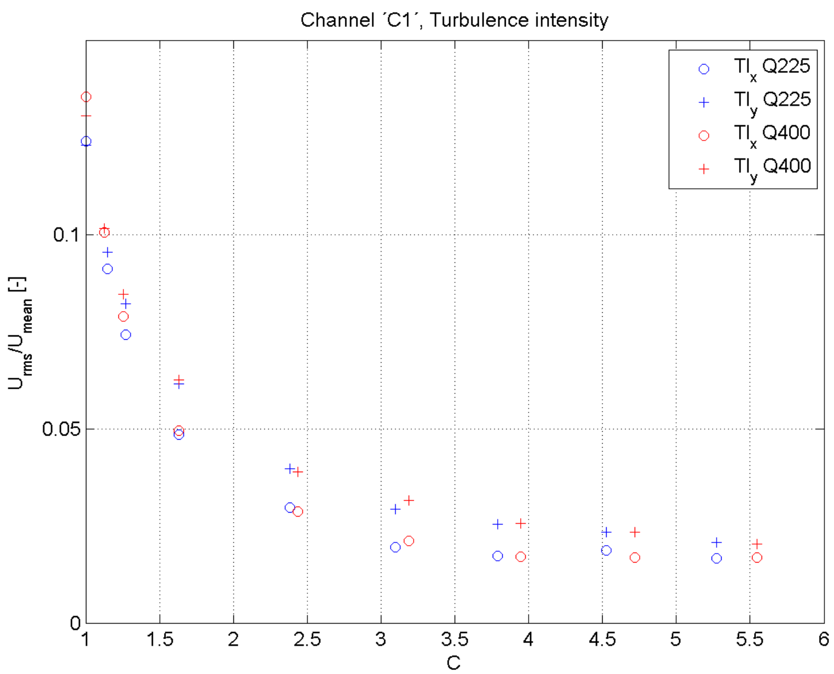
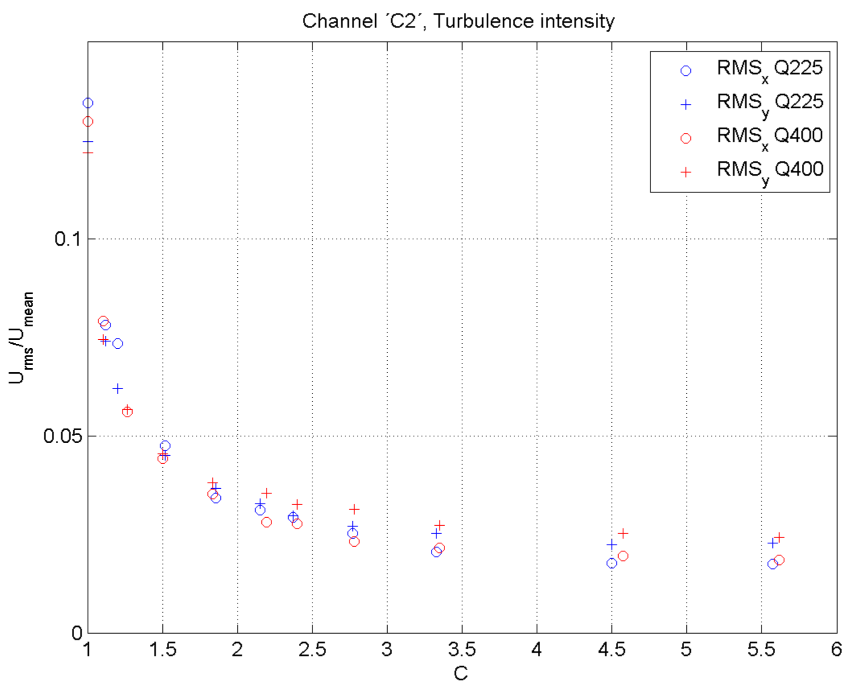
MD – acceleration profiles



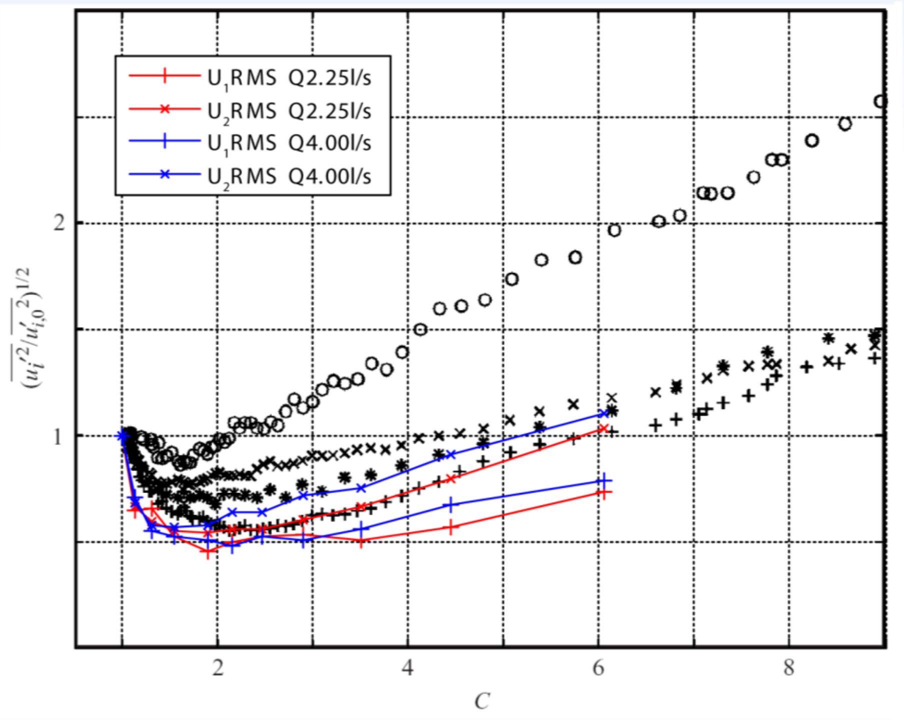
Turbulence


Channel ´C1´, Turbulence intensity
U_{rms}/U_{mean} [-]
C
TI$_x$ Q225
TI$_y$ Q225
TI$_x$ Q400
TI$_y$ Q400
0
0.05
0.1
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6


Channel ´C2´, Turbulence intensity
U_{rms}/U_{mean}
C
RMS$_x$ Q225
RMS$_y$ Q225
RMS$_x$ Q400
RMS$_y$ Q400
0
0.05
0.1
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6

Turbulence

Normalized RMS-velocities



Compared to the results of Parsheh et al. (2005), components: (+)=x_1, (x)=x_2

Fiber orientation

Fiber orientation results :

- Measurement method
- Orientation anisotropy
- Results & discussion

Fiber orientation measurements

Preparation of a fiber sample

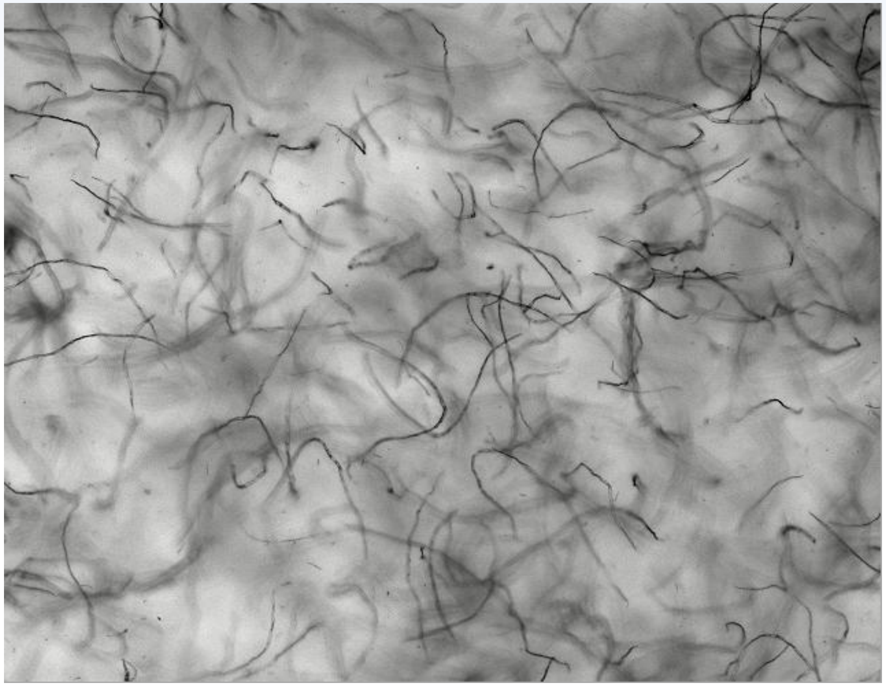
- Soaking, stirring, diluting
- Concentration 0.02 mass-%

Image analysis procedure

- More details in Eloranta et al. 2004
- Image preprocessing
- Division into subregions
- Radon transform
- Orientation propability (90° ...-90°)
- Averaging over 1000 images

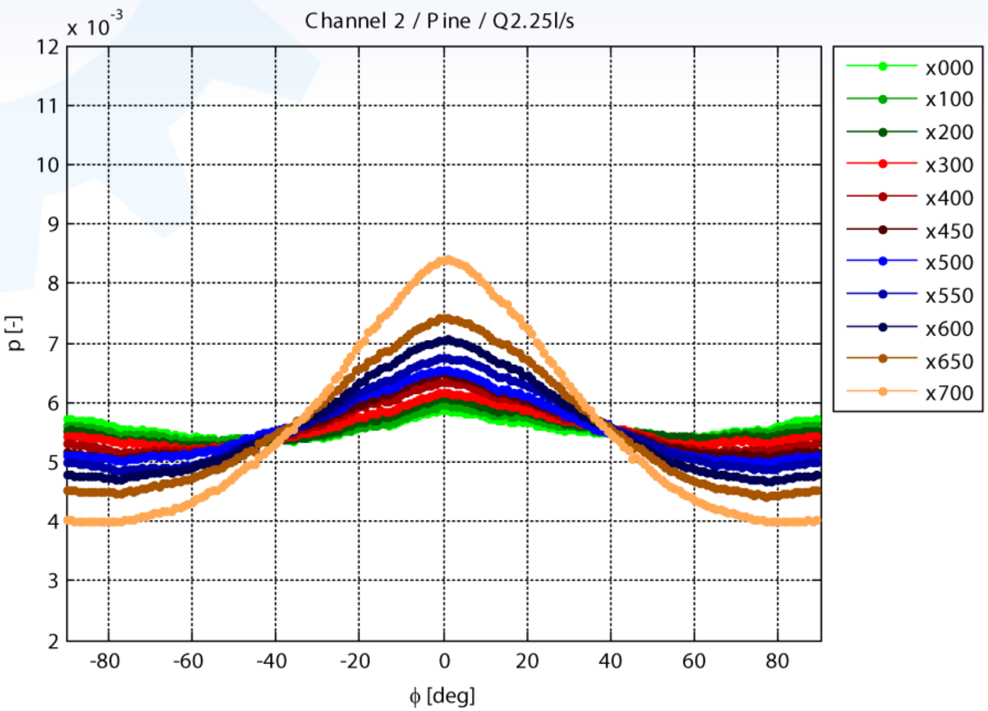
- Orientation anisotropy, defined as

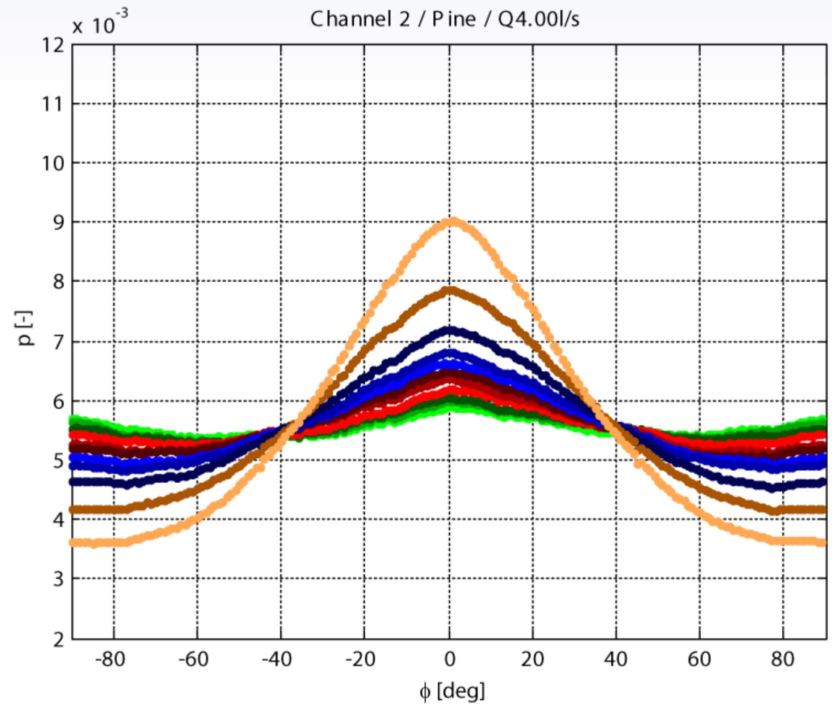
$$O(0°)\,/\,O(90°)$$



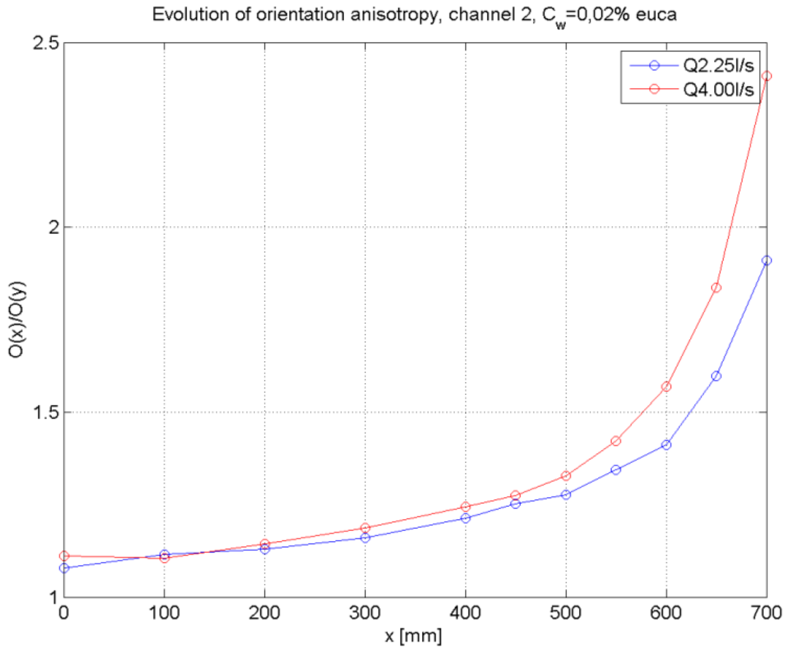
Pine fibers

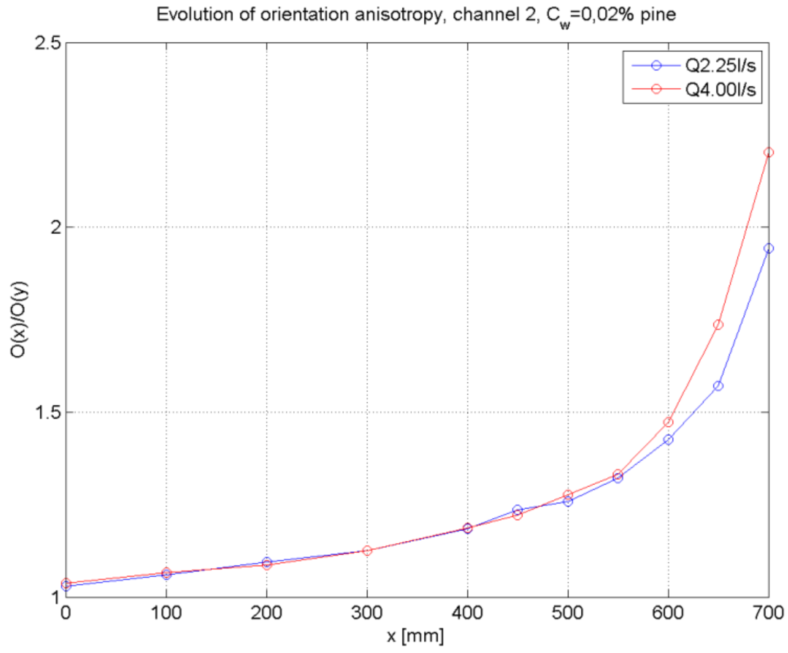
Fiber orientation results



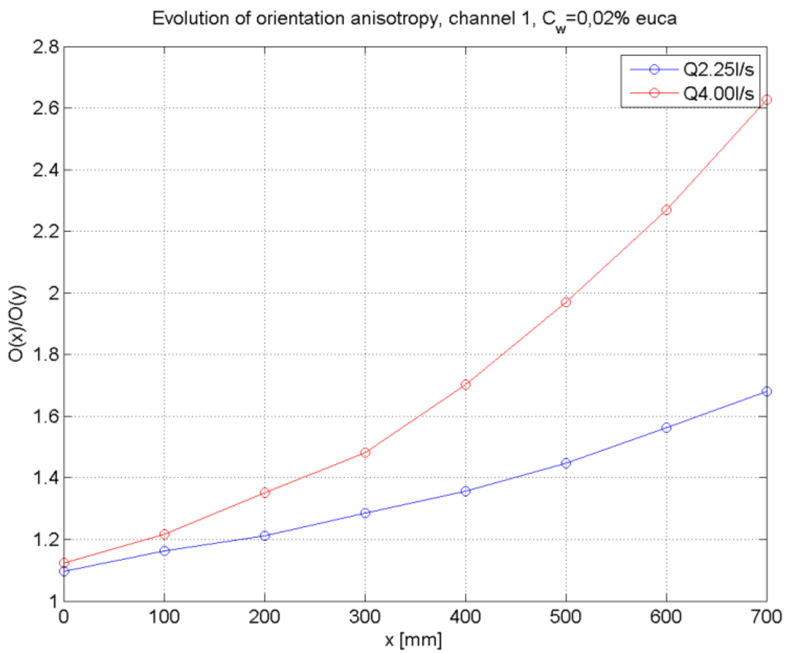


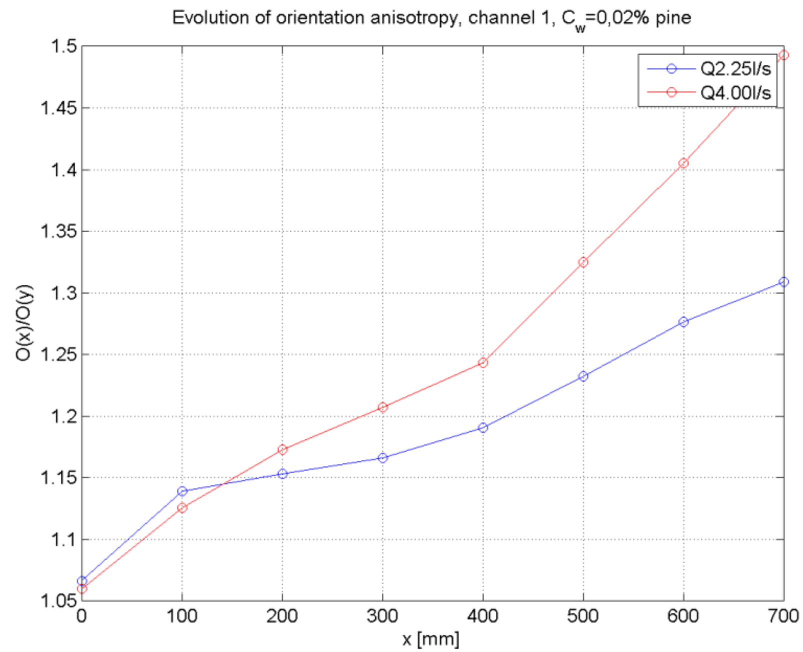
Orientation / Channel 2



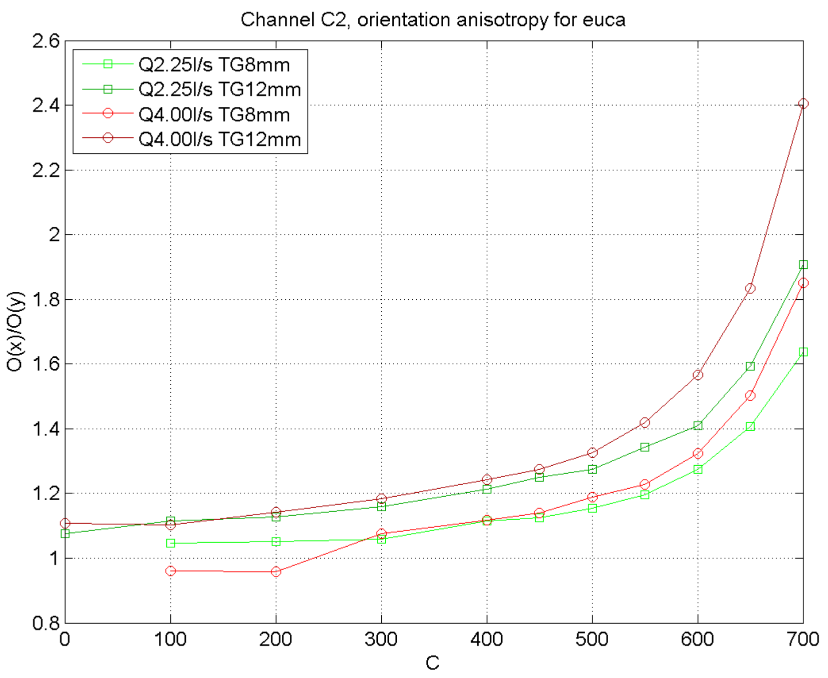


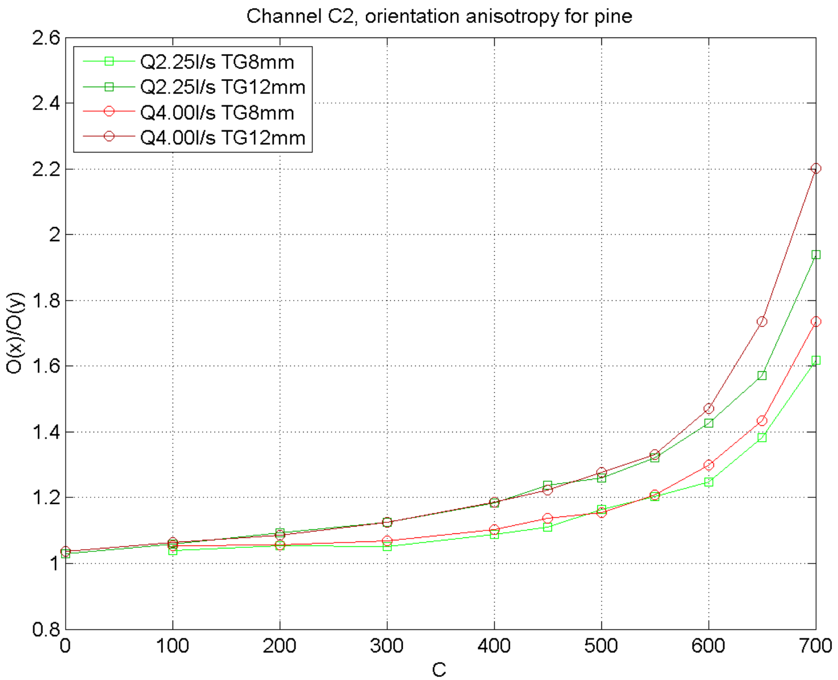
Orientation / Channel 1





Effect of turbulence





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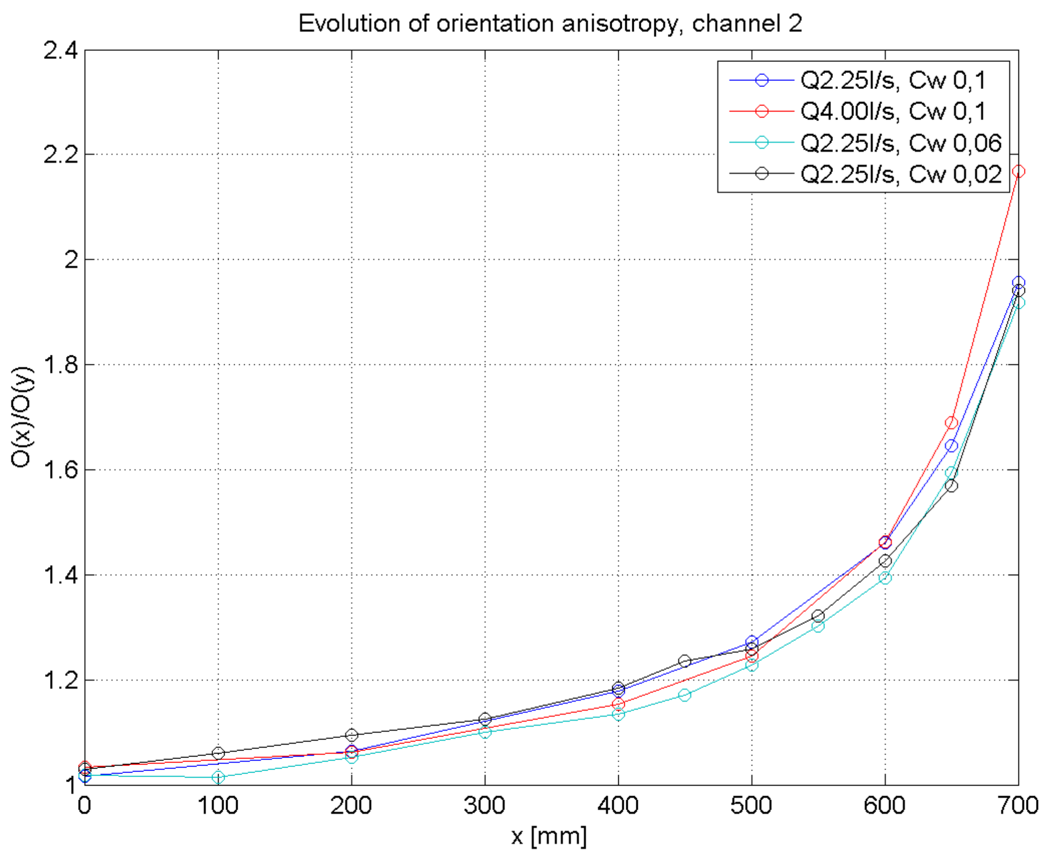
Effect of concentration



Results

Channel flow:

- Agreement with potential flow profiles good
- Turbulence decays rapidly, TI 13% → 3%
- profiles and anistropy of normalized RMS velocity components as in a wide channel

Fiber orientation:

- Clear orientation differences between fibers in same, controlled flow conditions
- In Channel 2 (linear contraction) orientation develops strongly within the last 100 mm of the channel, where the streamwise acceleration i.e. rate of strain is high, but TI low
- Fiber length seems not to be a sufficient factor to forecast differences in the development of orientation anisotropy
- Flow rate affects when fibers curly and flexible → streching, straightening
- Development of anisotropy close to linear as a function of C for all fibers, the slope different for different fibers

Thank you for your attention!