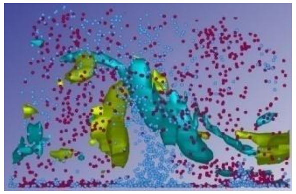
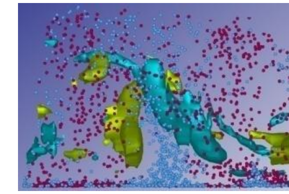


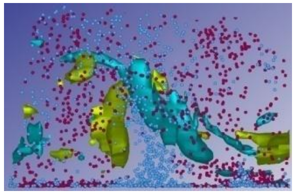
Characteristics of Fibre Suspensions in a Turbulent Pipe Flow

Stella Dearing*, Cristian Marchioli, Alfredo Soldati

Dipartimento di Energetica e Macchine,
Università di Udine, Italy



Contents



Applications: Which industries benefit

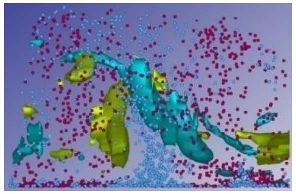
Inertial fibres suspended in turbulent flows are commonly encountered industry

- **Pulp and paper processing**
  - Controlling rheological behaviour and fibre orientation distribution crucial to optimise operations
- **Furniture Industry**
  - Pneumatic transport of fibres

- **Nappy Fabrication**
  - Fluff , cellulose fibres, make up 60% of nappy material. Uniform distribution is highly desirable for increased absorption

- **Fibres as an alternative to polymers as a DRA?**
  - Examples include the TAPs, medical application, firehouse
  - Fibres provide more modest reductions but improved shear degradation and filterability

Experimental data is required to validate simulation assumptions. Provide industry with practical correlations for sizing of industry equipment (*aim not to oversize*)

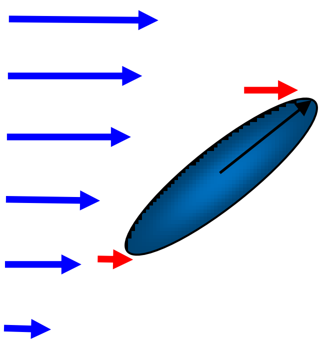


Motivation: Why Study?

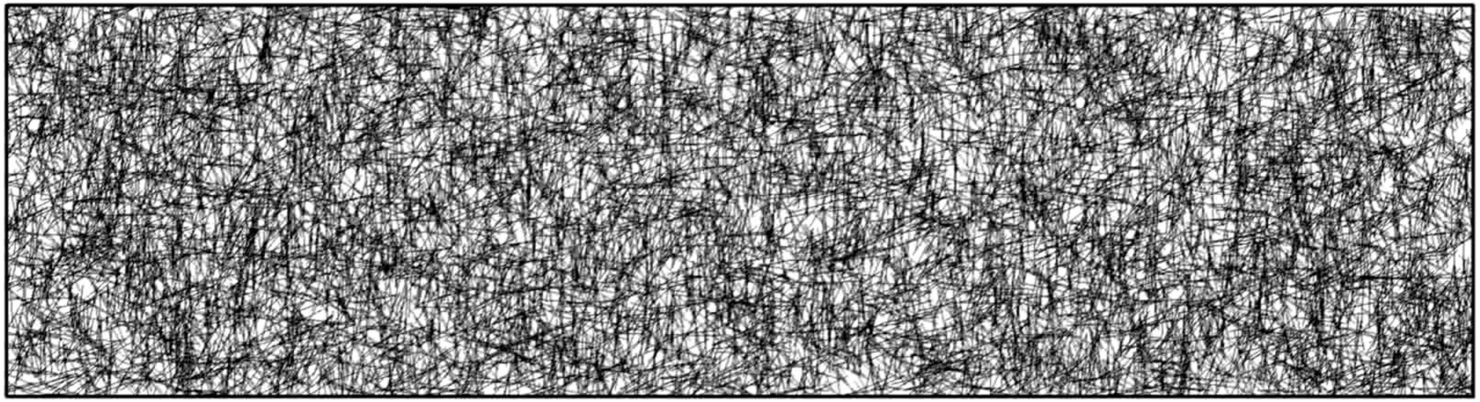
Fibre suspensions have complicated rheological properties that are quite different than carrier fluid even at low mass fractions

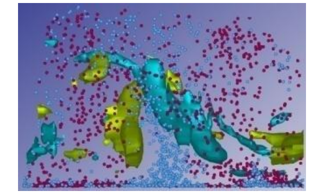
The physical properties depend on particle spatial distribution and orientation

1. **Fibres rotate/align** when subject to velocity gradient –hydrodynamic drag of fibres is f(rotational motion) → controls translational motion
2. Strong turbulence tends **to randomise orientation** **(BERNSTEIN &SHAPIRO)**
3. BUT **coherent structures** →interact with fibres causing segregation and accumulation **(MARCHIOLI et al. PHYS. FLUIDS. 2010)**
4. Where **flocculation** occurs (network) an momentum adding/momentum reduce effect can occur

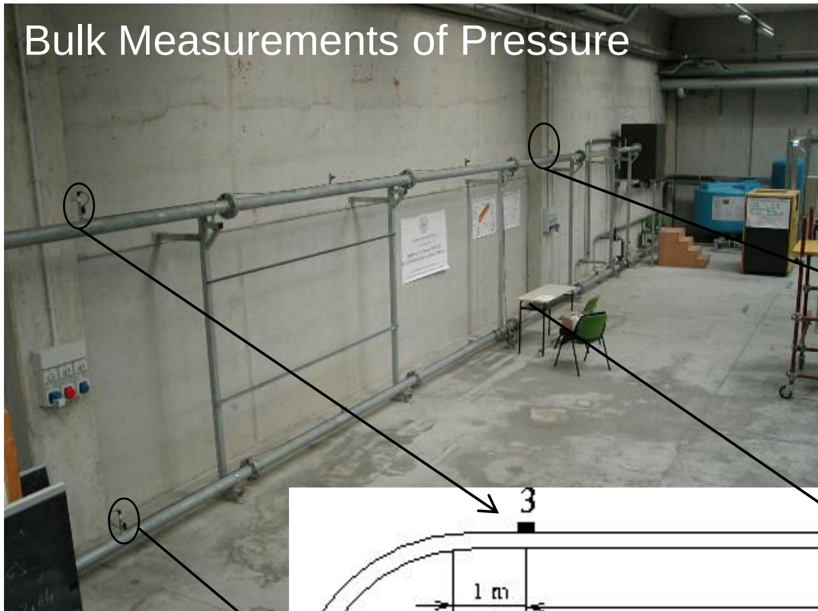


→Size(s) of fibre relative to turbulent structures



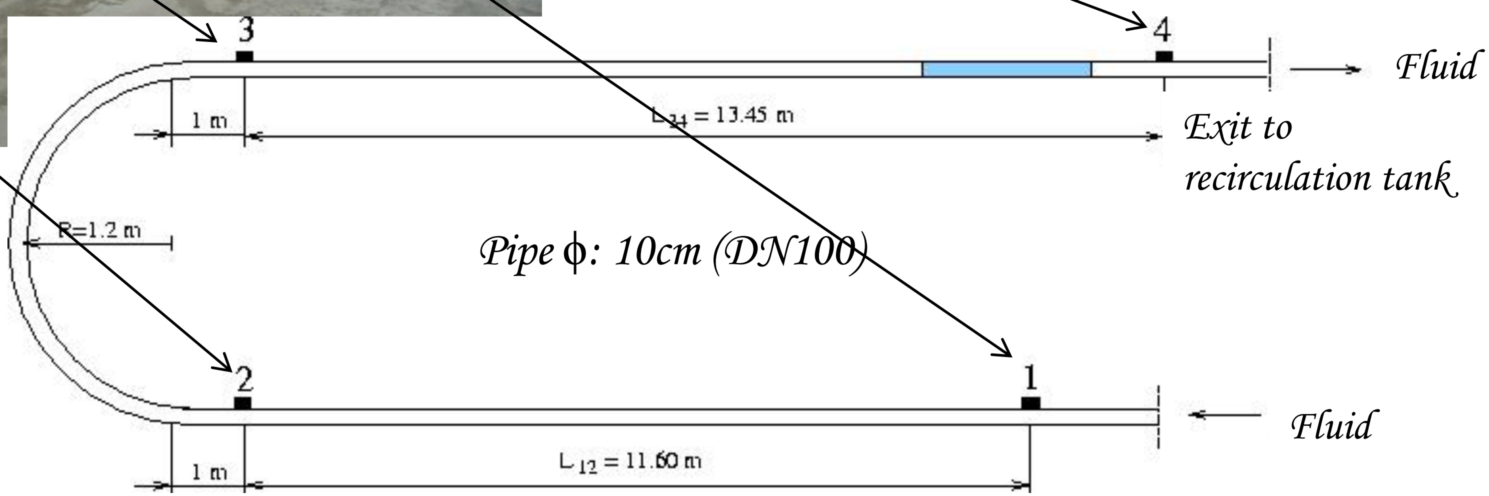


Set-up: Pipe Circuit measurements

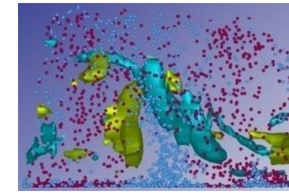


- IMPRESS Pressure transducers 0-400mBar gauge; 1% FS accuracy
- Coriolis force mass flow rate meter ± 0.01 m/s

Pipe length	31m
Pipe diameter	0.1m
Re	25000-250000
η	66-28 microns

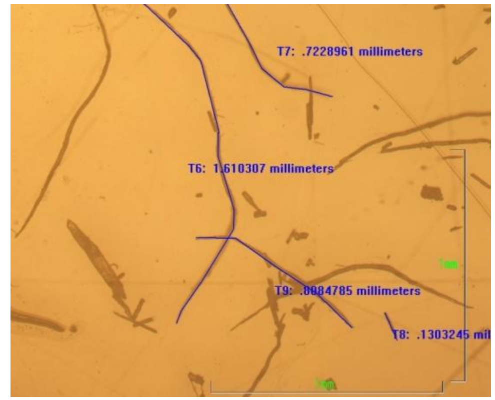


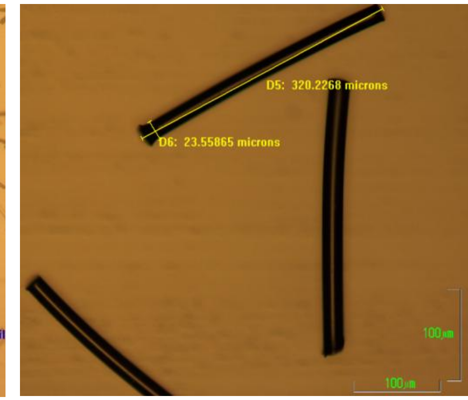
Experimental Parameters

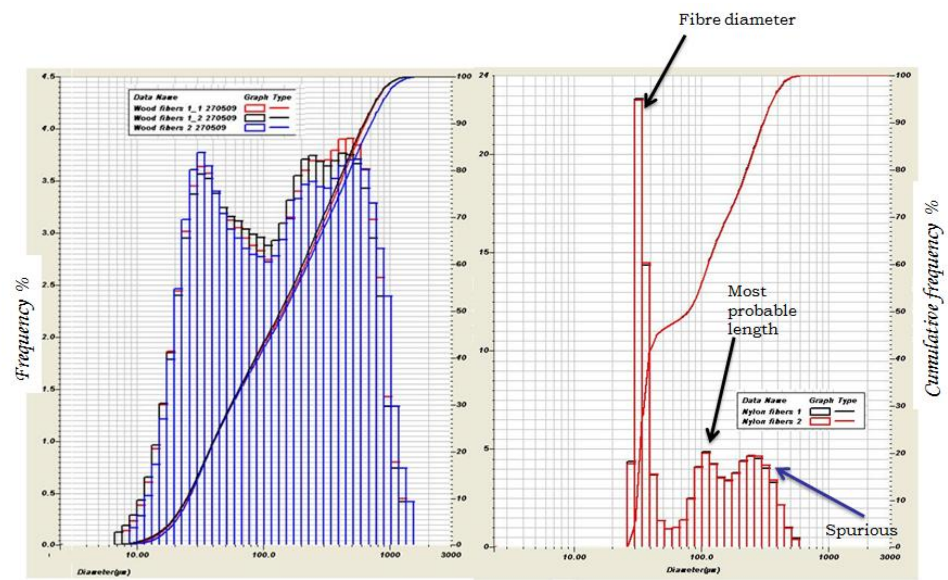


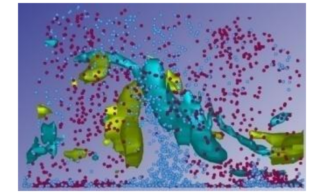
Additive	Length	Diameter	Density
Wood	~1mm-0.01mm	20μm	0.763
Nylon	~.3mm	24μm	1.14
XG	~1000nm	2.6nm	0.9

Fibre type	Mass fraction, ϕ, %	nL^3
Nylon	0.01	0.018
	0.02	0.035
	0.05	0.089
	0.1	0.177
	0.5	0.890
	1	1.78
Wood	0.01	0.073
	0.05	0.363
	0.1	0.725
	0.5	3.633
	1	7.298
Xanthan Gum	0.05	0.002
	0.1	0.004
	0.15	0.007

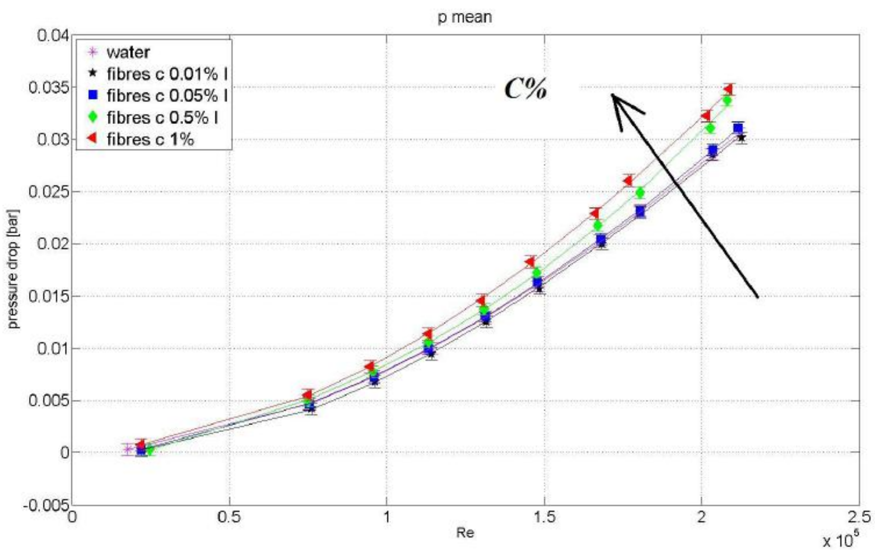


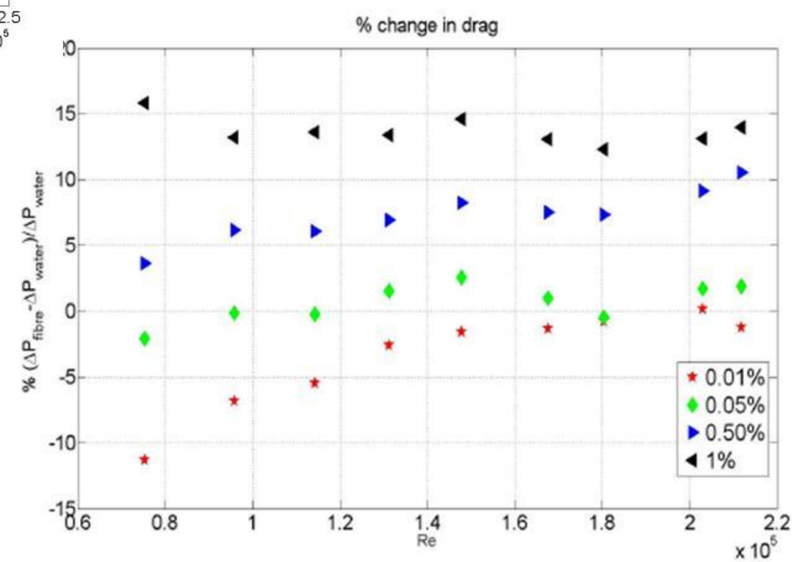




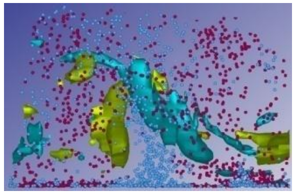


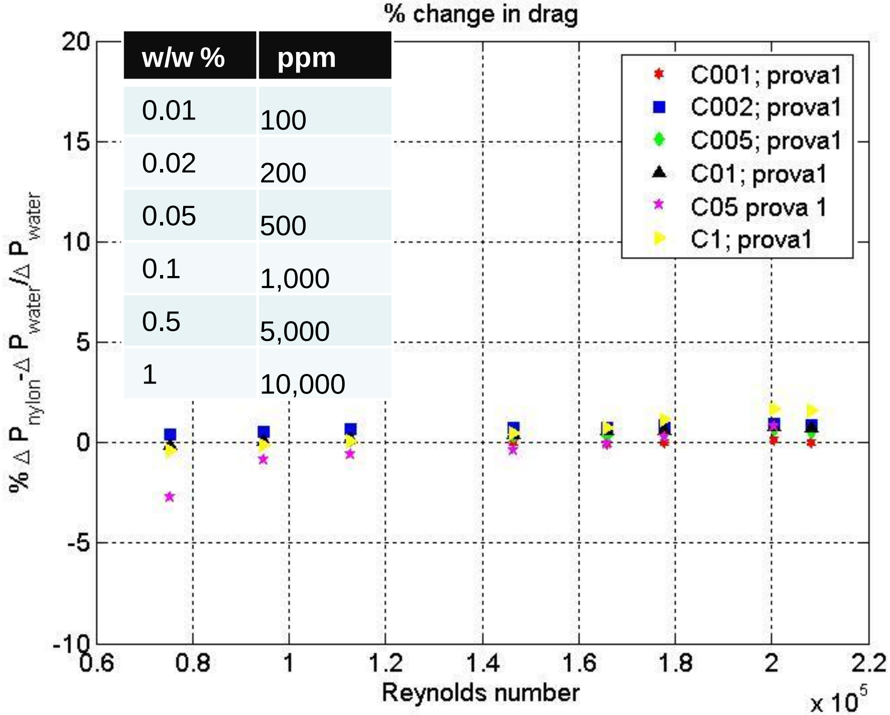
Pressure drop results: wood



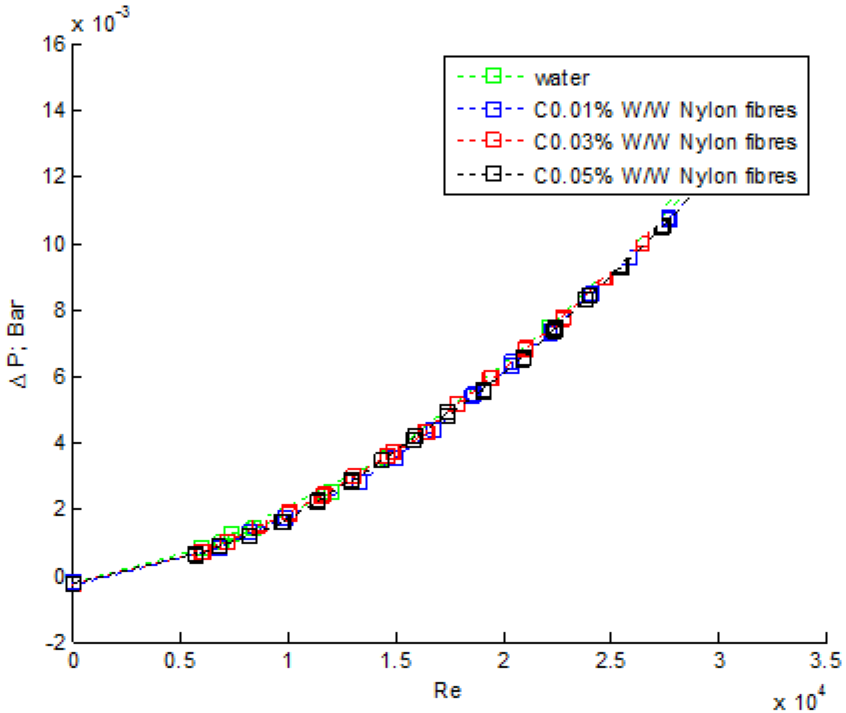


Pressure drop results: Nylon





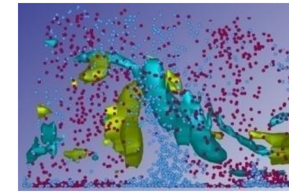
w/w %	ppm
0.01	100
0.02	200
0.05	500
0.1	1,000
0.5	5,000
1	10,000



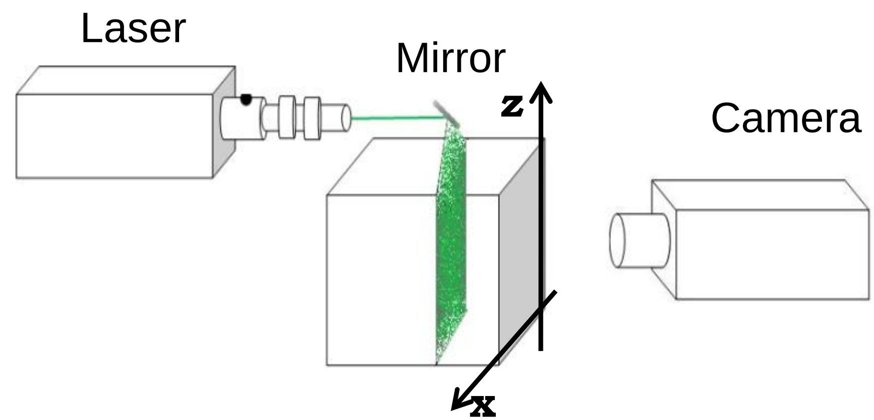
Nominal pipe diam.	Reynolds number	Fiber conc., wppm	Fiber additive
2.4 cm	10^5	1,000 nylon	15
4.9 cm	5×10^4	1,000 nylon	17

→No/little change in pressure losses

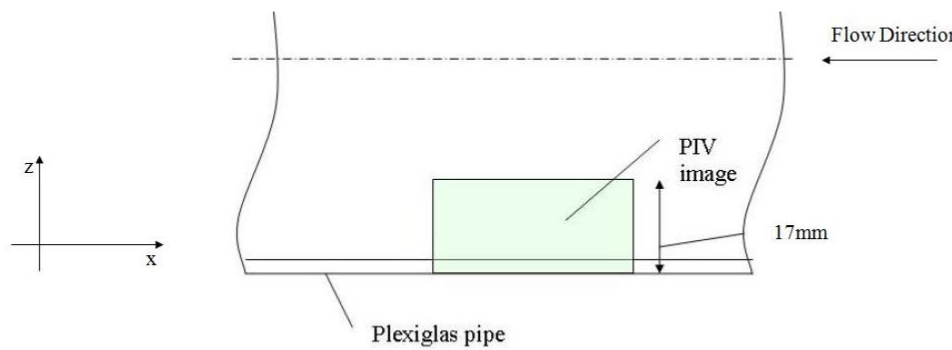
→in contrast with previous work (w. **K. LEE, R. C. VASELESKI & A. B. METZNER**)



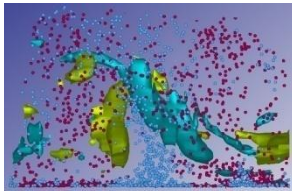
Set-up: Pipe Circuit measurements



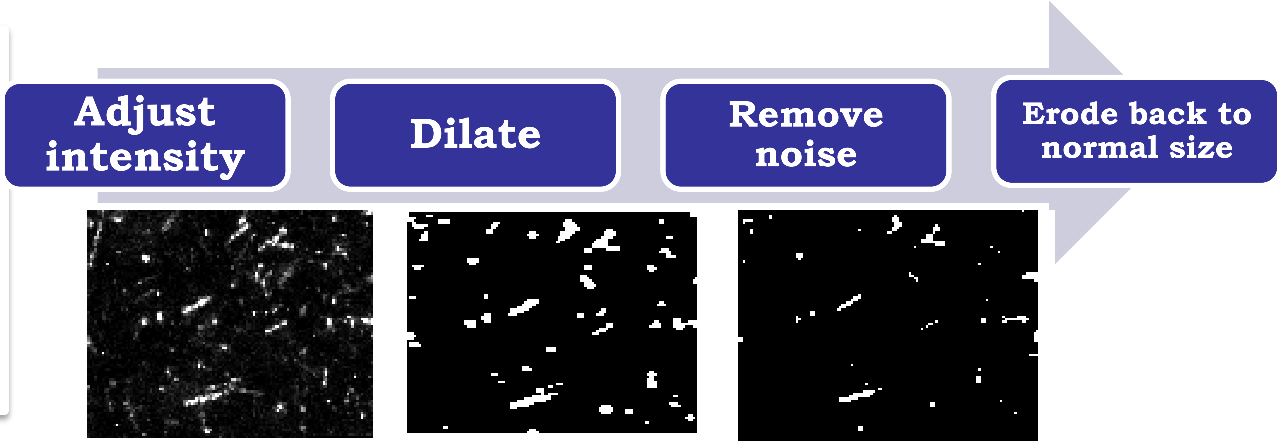
- System details:
  - PCO sensicam 1280 x1024
  - ND Yag laser 1000mJ
  - F = 8hz



Software development: Phase Discrimination

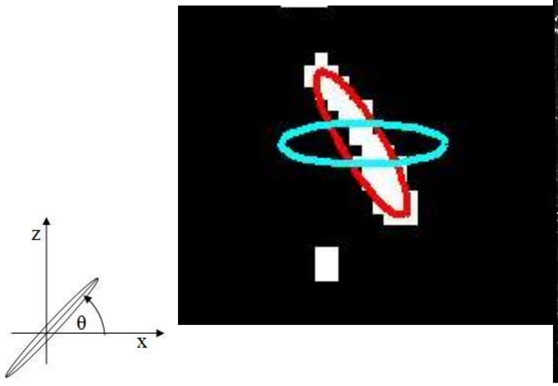


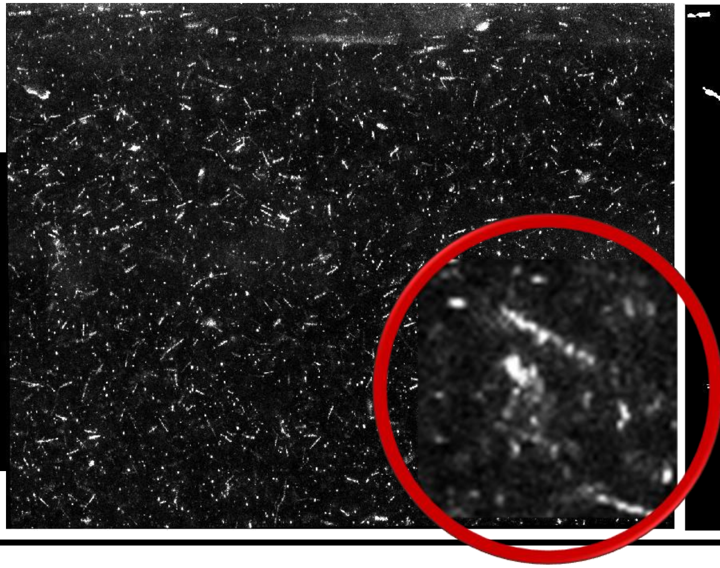
1. Preprocessing
2. Object Identification
3. Discriminate objects based on length and aspect ratio
4. Ellipse fitting

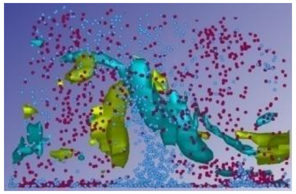


$$F(x,z) = ax^2 + bxz + cz^2 + dx + ez + f = 0$$

$$min_{\vec{a}} \sum_{i=1}^{N} F(x_i, z_i)^2 = min_{\vec{a}} \sum_{i=1}^{N} (\vec{X}_i \bullet \vec{a})^2$$





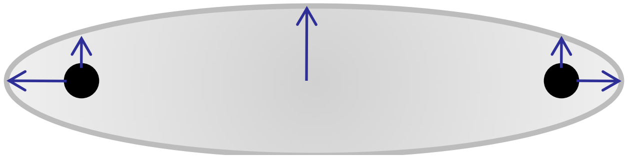


Software development: Artificial Image

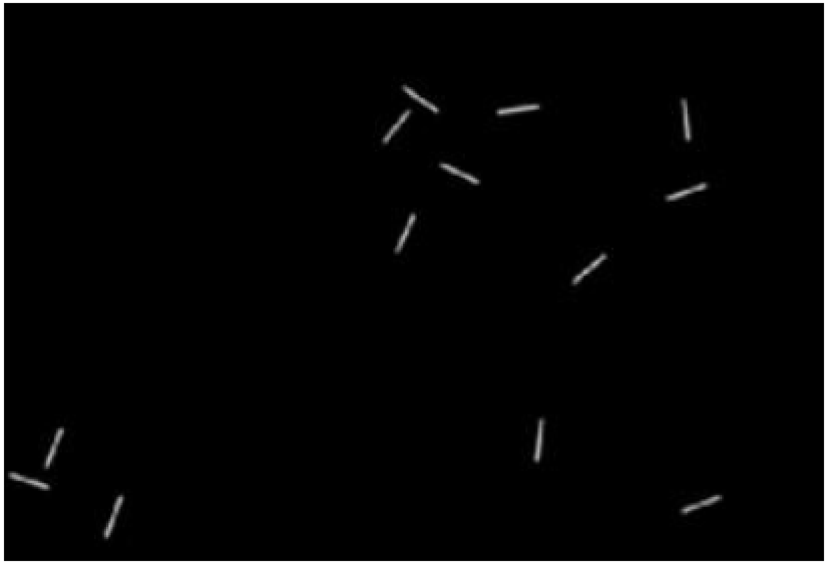
Artificial images

$$I_o(z) = q\ exp\left[-\frac{z^2}{\frac{1}{8}\Delta z_o^2}\right] \qquad I(x') = I_o exp\left[\frac{-(x'-x'_o)^2}{\frac{1}{8}d_\tau^2}\right]$$

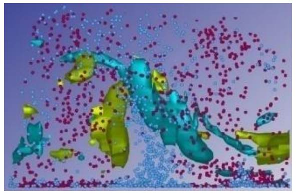
- **Extension of intensity distribution of a spherical particle**
  - Intensity is gaussian along width of fibre
  - Does not change along length until focal points



$$I(x',y') = I_o exp\left[\frac{-(x'-x'_f)^2-(y'-y'_f)^2}{\frac{1}{8}d_\tau^2}\right]$$

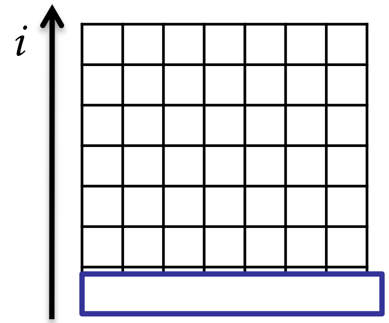


- **Recreate experimental conditions**
  - Create image larger than actual image
  - Crop to size
  - Includes partially captured fibres as expected a laser sheet



Test Cases:

1. Aspect ratio 20, no s/w orientation and no intersecting fibres: 2 % underprediction
2. Aspect ratio 20 with no s/w orientation but intersecting fibres : 5 % underprediction (requires higher number of images for convergance)
3. Aspect ratio 20 with s/w orientation and intersecting fibres 25 % overprediction for random distribution; 15% for aligned distribution



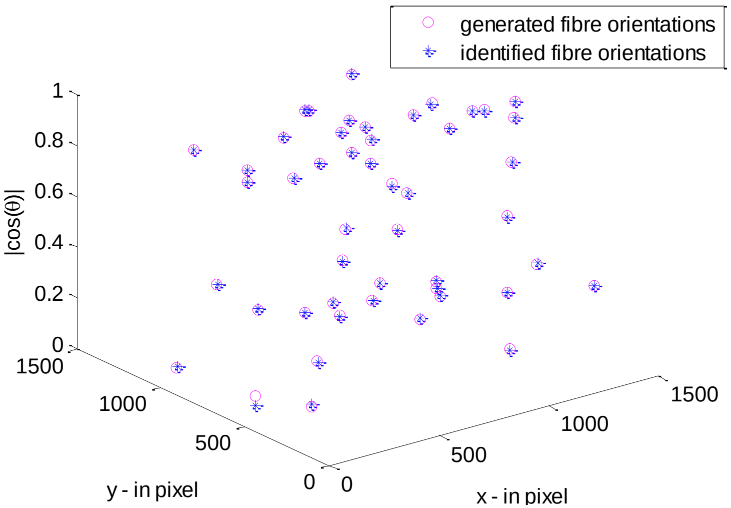
Mean orientations

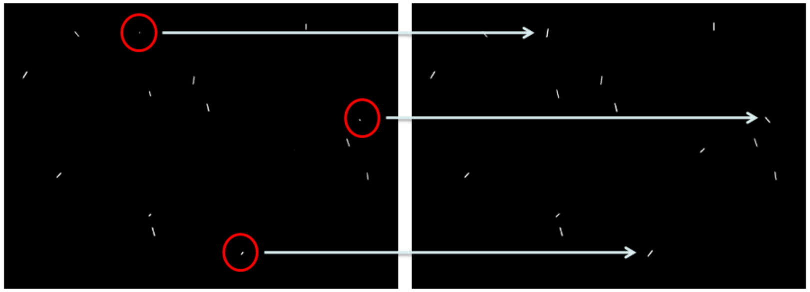
$$< cos(\theta_x) >= \frac{1}{N_{p,i}} \Sigma_{k=1}^{N_{p,i}} cos(\theta_x)$$

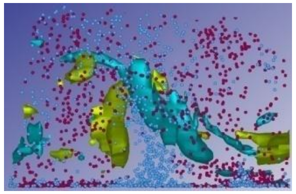
Normalised number density

$$< N >= \frac{1}{N_{p,i}} \Sigma_{k=1}^{N_{p,i}} N$$

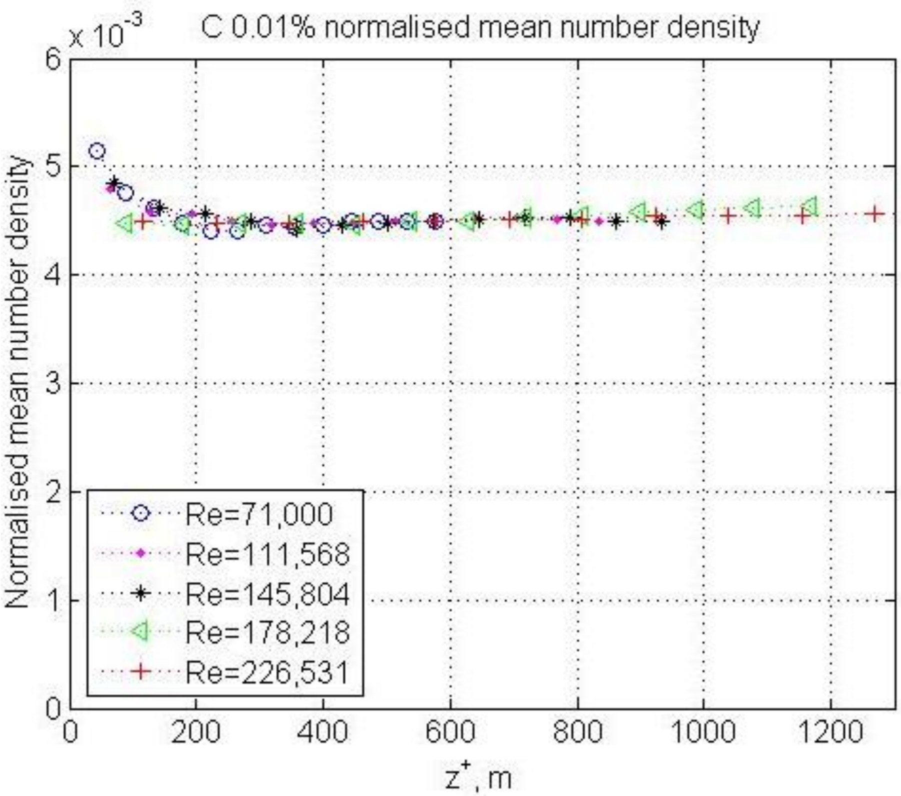
Projected fibre onto plane → over prediction compared to 3D case by 20%

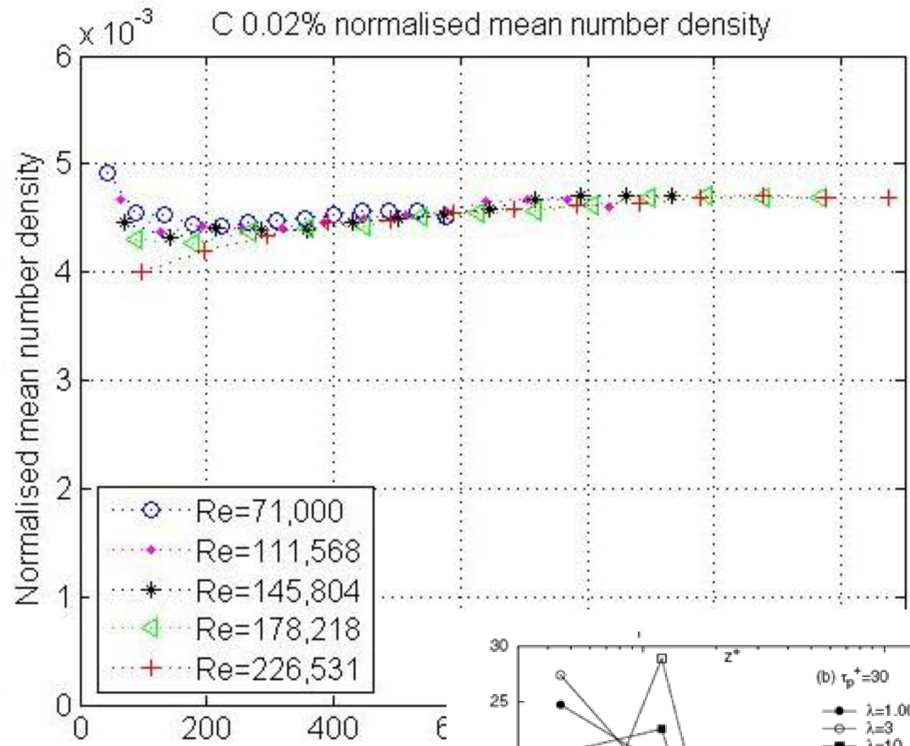


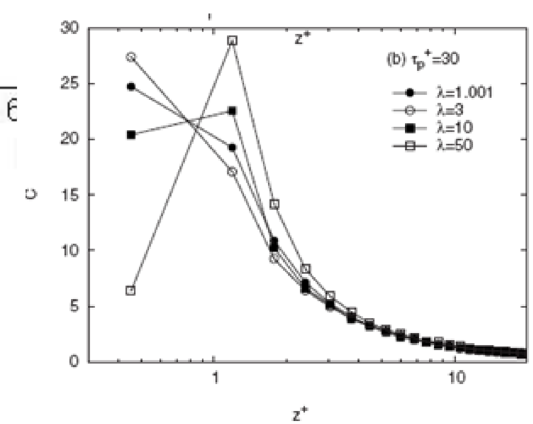




Results: Normalised mean number density

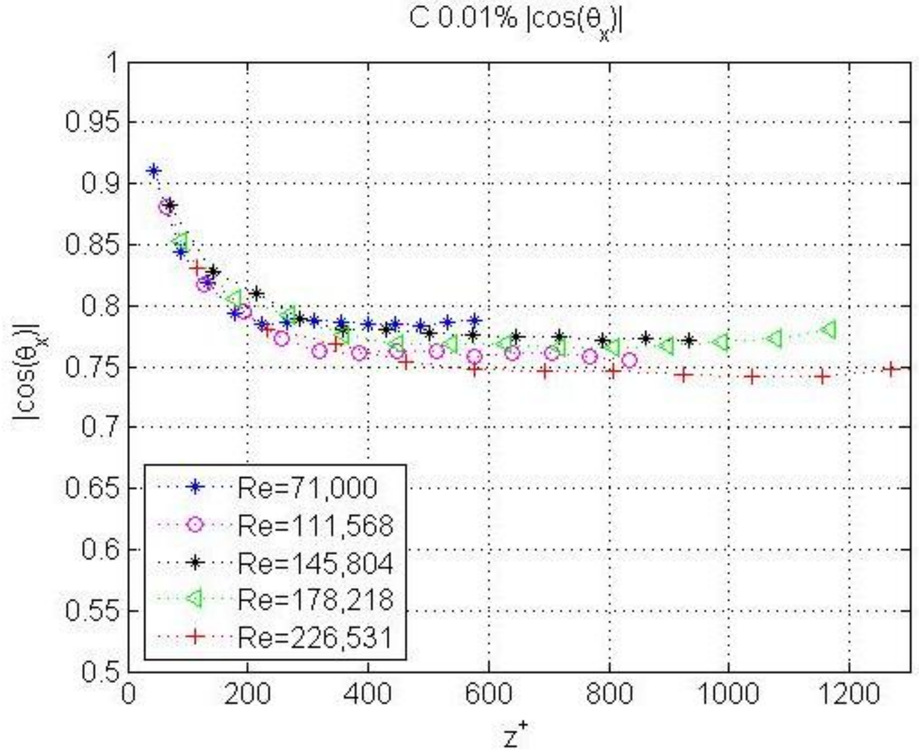


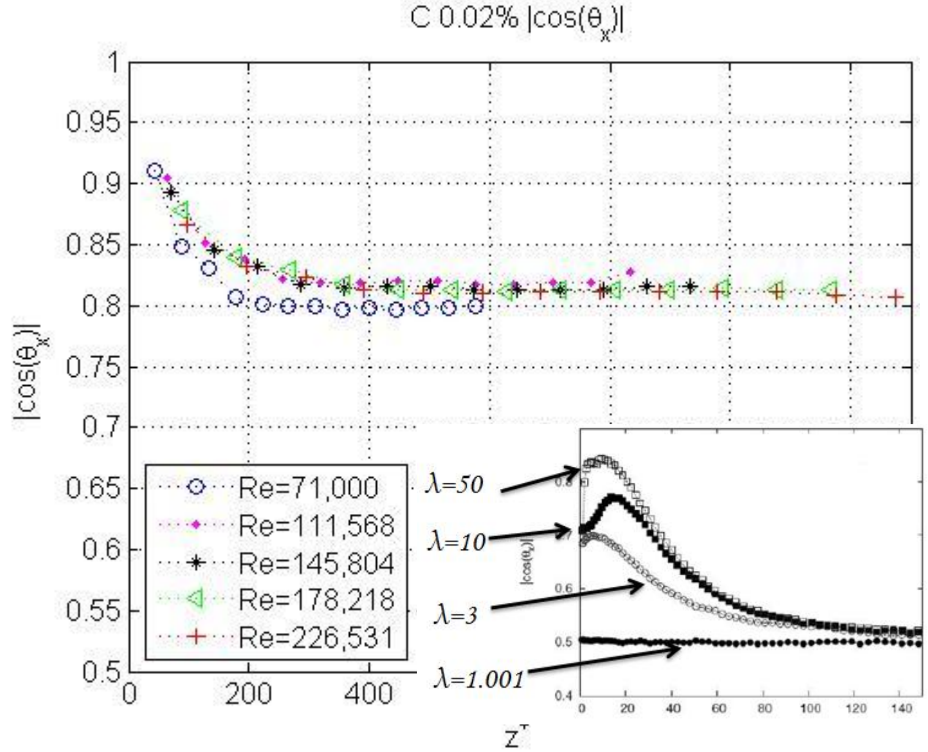




- ❑ **Instantaneous concentration profiles** volumetric fiber number density
- ❑**Near wall peak**
- ❑**Decrease of concentration** at z+ approximately 1- after which point λ has little or no effect on concentration profiles

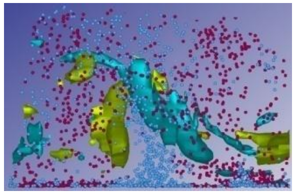
Results: Mean orientations





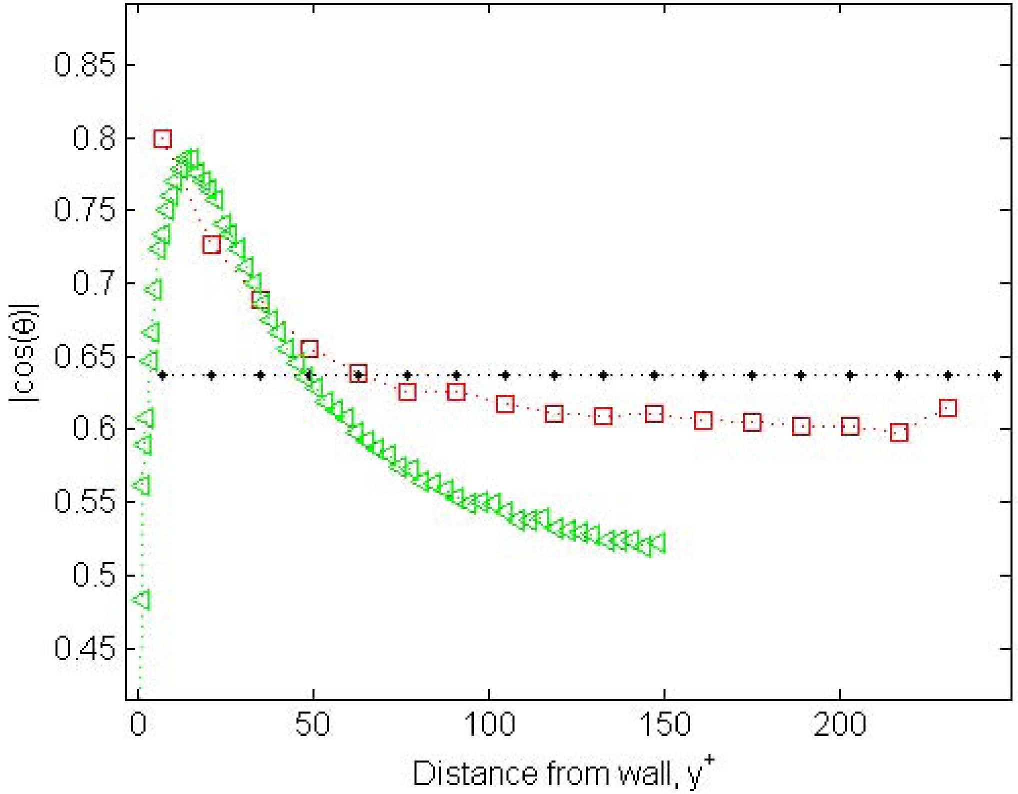
•Fibres tend to align in the **streamwise direction**
• Preferential orientation increases with **aspect ratio** and decreases with **inertia**

Results: Mean orientations

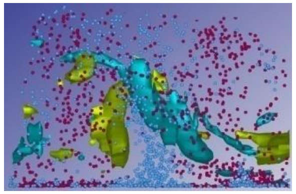


Results → mean orientation

Green triangles → DNS data (Marchioli et al., 2010) at Re = 9000,
Red squares →experimental data Re = 8043



Projected fibre onto plane → random distribution tends to 0.64 vs 0.5



Conclusions

- No drag reduction for macroscopic fibre additives (pressure drop & PIV results)
  - For more detailed information on decomposed flow field we are in the process of doing error analysis of phase discrimination PIV algorithm using a DNS flow field
- Dimensional arguments back this up
- Mean orientation and number density data qualitatively agrees with DNS data → promising.
  - Results for smaller Re_{τ}
  - Analysis of DNS results
- How to convert number densities to concentrations. This is a an important issue when using PIV for non spherical particle