Test case

Dispersion of rod-like particles in a turbulent free jet

1. MOTIVATION:

Turbulent particle dispersion is a fundamental issue in a number of industrial and environmental applications. An important class of turbulent two-phase flows is represented by jets, which represent a baseline case and a starting point for approaching more complex flows. Particle-laden turbulent jets have been largely investigated to examine problems such as flow-induced particle distribution and concentration and particle-induced turbulence modifications. Almost all available investigations consider a dispersed phase made of spherical particles: However, in many situations (e.g. pulp production, paper manufacturing, cloud formation), the dispersed phase cannot be deemed as spherical and is better approximated by rod-like particles, characterized by high (> 5) geometrical aspect ratio.
Although some experimental and numerical works already focus on fiber suspensions in turbulent flows (for instance see Krochak et al. (2008), Parsa et al. (2011), Marchioli et al. (2010) among others), there are few experimental studies on the effects of rod-like, fiber particles in jet flows e.g. Lin et al. (2012). As a result, the physics of turbulence modulation effects in fiber-laden flows as compared to spherical particles is far less known. In addition new and reliable experimental data are required to tune numerical modeling.

The objectives of this benchmark are to have a large number of people working on the same specific problem and to establish a validated numerical dataset that can reproduce in a reliable and accurate way available experimental measurements:

- *reliable and accurate velocity statistics for the fluid field, the particle field and the fluid field at the particle position (mean and rms velocities, Reynolds stresses);*
- *particle concentration profiles.*

Once validated, the numerical dataset can be used to obtain further statistics, such as:

- *one-particle statistics (e.g. particle velocity auto-correlations, particle mean-square displacements, Lagrangian integral time scales);*
- *two-particle statistics (e.g. rms particle dispersion).*

To these objectives, sinchronized activity among participants is required.

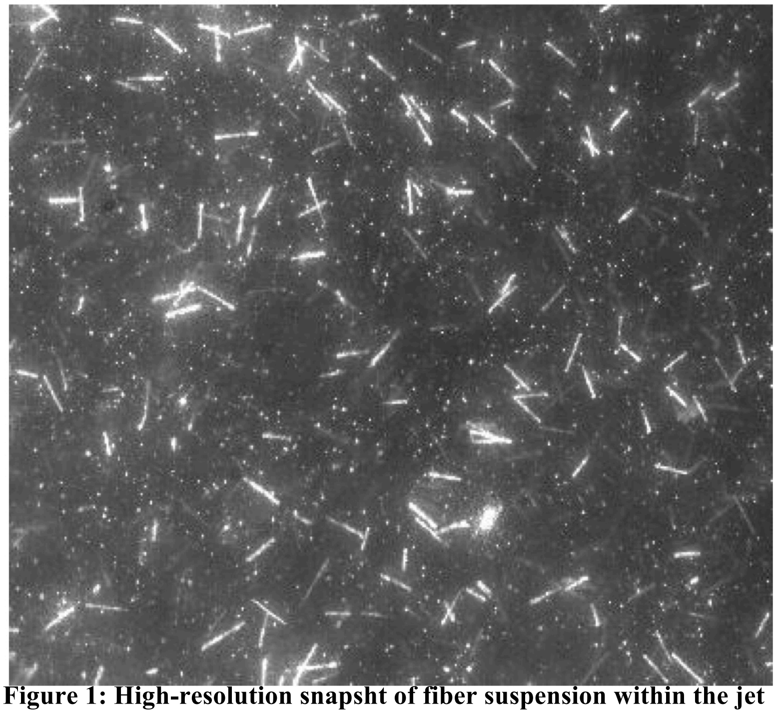


Figure 1: High-resolution snapsht of fiber suspension within the jet

2. GUIDELINES FOR PARTICIPANTS:

The general objective of the test case is to validate numerical predictions obtained by different model approaches and numerical codes. Therefore participants are asked to reproduce numerically the PIV measurements of the fiber-laden turbulent round jet (reported in Ref. [1]) using the data provided in Section 3.
Results will be presented in poster form at the 14th Workshop on Two-Phase Flow Predictions to be held in Halle, September 7-10, 2016 (http://www-mvt.iw.uni-halle.de/workshop15/workshop15.html).

3. PARAMETERS OF THE BENCHMARK SIMULATION:

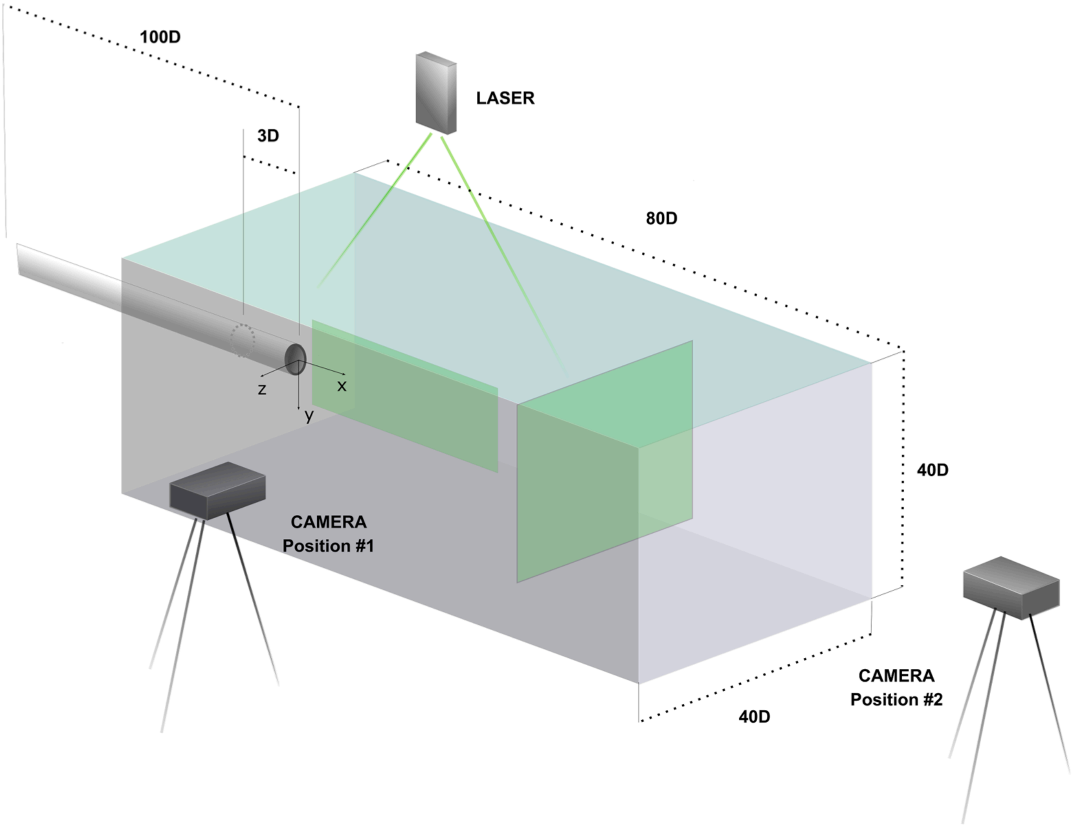
Simulation should be run to reproduce exactly the experimental set-up described in [1], which is summarized in the following.

3.1 Fluid (water):

Jet Reynolds number: $Re=U_0D/\nu = 9000$ with:

$U_0=0.41\ m/s$ (jet bulk velocity based on a kinematic fluid viscosity $\nu=10^{-6}\ m^2/s$)
$D=2.2\ cm$ (jet diameter)

•Physical flow domain:



- Pipe: roughness $\varepsilon = 0.015mm$, diameter $D = 2.2\ cm$ (inlet jet diameter), length $L=100D$
- Observation tank: length: $L=80D$, width $W=40D$, height $H=40D$

- Acquisition window: x-y plane an area of approximately 5.5D x 2D (spatial resolution of 0.12 mm/pixel corresponding to 0.006D).
- PIV system:
    - Camera: 8-bit BW, Photron APX CMOS camera (resolution: 1024 x 1024 pixels, frame rate: 500 Hz)
    - Camera objective: Nikon F 50 mm focal length with maximum aperture of 1.2
    - Lighting: continuous Spectra Physics Ar-ion laser, 488– 514 nm in wavelength, with a maximum power equal to 7W.

3.2 Rod-like particles:

Nylon fibers (Polyamide 6.6, produced by Swissflock AG) with:

- mean diameter $d_p=24\,\mu m$, mean length $l=320\,\mu m$ (-> aspect ratio $l/d_p=13.3$)
- density $\rho_p= 1150\ \ kg/m^3$ (-> $S=\rho_p/\rho = 1.15$)
- estimated Stokes number*: $St=0.7$

* Stokes number: $St = \tau_p/\tau_f$ with $\tau_p = \frac{d_p^2 S \ln(\lambda+\sqrt{\lambda^2-1})}{18\mu\sqrt{\lambda^2-1}}$ and $\tau_f = U_0^2 / \nu$.

Mass fractions: 0.0020% (case C1), 0.0060% (case C2)
Volume fractions: 0.0017% (case C1), 0.0052% (case C2)

3.3 Tracers:

Neutrally-buoyant hollow glass spheres (Dantec HGS-10) with diameter 10 μm and $St=0.0002$.

4. AVAILABLE DATA

The available data were obtained from an experimental campaign on pipe jet flow laden with fiber-like particles (see Ref. [1]). Data are provided in the form of csv files that can be read by Excel or OpenOffice. Each file is named according to the following rule:

<fu/fv/u/v/uv>_<empty/m/r>_<axi/rad>_<s0/f1/f2><empty/_01/_05>.csv

where:
fu is the axial fiber velocity component
fv is the radial fiber velocity component
u is the axial fluid velocity component
v is the radial fluid velocity component
uv is the fluid turbulent stress
m represents a mean quantity
r represents the rms
axi indicates data taken along the jet axis y/D=0
rad indicates data that refer to the radial direction
s0 indicates the unladen jet case
f1 indicates the laden jet case C1 (0.0020% mass fraction)
f2 indicates the laden jet case C2 (0.0060% mass fraction)
_01 indicates data taken along the radial direction at the axial location x/D=1
_05 indicates data taken along the radial direction at the axial location x/D=5

Therefore, the following data are made available:

- Single-phase flow data for validation
  - centerline velocity measurements (mean, rms and Reynolds stress)
  - profiles for the single phase flow at different axial positions (x/D = 1 and 5)
- Two-phase flow with 0.0020% mass fraction (case C1)
  - Gas-phase velocities (axial and radial components; mean, rms and Reynolds stress) at different axial positions (x/D = 1 and 5)
  - Axial fiber velocity (mean and rms) along the jet axis
  - Axial fiber velocity /mean and rms) along the radial direction
- Two-phase flow with 0.0060% mass fraction (case C2)
  - Gas-phase velocities (axial and radial components; mean, rms and Reynolds stress) at different axial positions (x/D = 1 and 5)
  - Axial fiber velocity (mean and rms) along the jet axis
  - Axial fiber velocity (mean and rms) along the radial direction

5. DATA TO BE PROVIDED

To compare simulations with measurements for the two laden jet test cases the following data should be provided in separate EXCEL sheets:

Centre line velocities of the gas phase (normalized by the reference velocity U_0) for cases C1 and C2 up to x/D = 5.5:

x/D	u_m / U_0 [-]	u_{rms} / U_0 [-]	v_m / U_0	v_{rms} / U_0 [-]
…	…	…	…	…

Centre line velocities of the fibers (normalized by the reference velocity U_0) for cases C1 and C2 up to x/D = 5.5:

x/D	$u_{f,m} / U_0$ [-]	$u_{f,rms} / U_0$ [-]
…	…	…

Profile of fluid velocities (normalized by the reference velocity U_0) for case C1 and for case C2 at axial positions x/D = 1 and x/D=5 in a radial range $-1.26 < r/D < 1.26$:

x/D	u_m / U_0 [-]	u_{rms} / U_0 [-]	v_m / U_0	v_{rms} / U_0 [-]	$u'v' / U_0^2$ [-]
…	…	…	…	…	…

Profile of fiber axial velocity (normalized by the reference velocity U_0) for cases C1 and C2 at axial positions x/D = 1 and x/D=5 in a radial range $-1.26 < r/D < 1.26$:

x/D	$u_{f,m} / U_0$ [-]	$u_{f,rms} / U_0$ [-]
…	…	…

6. REFERENCES:

[1] Capone A, Soldati A, Romano GP (2015) Experimental investigation on interactions among fluid and rod-like particles in a turbulent pipe jet by means of Particle Image Velocimetry, *Exp. Fluids*, vol. 56, issue 1.

[2] Capone A., Soldati A, Romano GP (2013) Mixing and entrainment in the near field of

turbulent round jets, *Exp Fluids*, vol 54, pp. 1434.
[3] Krochak P, Olson J, Martinez D (2008) The orientation of semi-dilute rigid fiber suspensions in a linearly contracting channel flow. Phys Fluids, vol. 20, pp. 073303
[4] Lin JZ, Liang XY, Zhang SL (2012) Numerical simulation of fiber orientation distribution in round turbulent jet of fiber suspension. *Chem Eng Res Des*, vol. 6, pp. 766-777.
[5] Marchioli C, Fantoni M, Soldati A (2010) Orientation, distribution and deposition of elongated, inertial fibres in turbulent channel flow. *Phys Fluids*, vol. 22, pp. 033301.
[6] Parsa S, Guasto J, Kishore K, Ouellette N, Gollub J, Voth G (2011) Rotation and alignment of rods in two-dimensional chaotic flow. *Phys Fluids*, vol. 23, pp. 043302

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