EXPERIMENTS AND DNS OF A ROUND JET WITH TURBULENT INLET

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Abstract
Experimental and Direct Numerical Simulation data of a turbulent round jet fed by a turbulent pipe are compared in the near field. The Reynolds number achieved in both the experiment and the simulation, $Re = 16000$, allows a direct comparison of both the average and the fluctuating velocity statistics. In the experiments the jet is fed with olive oil droplets with a Stokes number $St \simeq 1$ whose dynamics is compared against the corresponding DNS simulation to asses the ability of particles to reproduce high order turbulence statistics and to asses the accumulation properties of inertial particles in the near field.

INTRODUCTION

Turbulent jets at low Reynolds number (less than 50000) are relevant for several engineering contexts, e.g. mixing, combustion, propulsion and biomedical applications [1]. Particle-laden turbulent jets also occur in many cases, e.g. coal combustion and chemical processes. Moreover, the coupling of the particle dynamics with the jet entrainment may affect the dynamics of droplet evaporation/condensation in clouds or spray injectors [6]. Therefore, the accurate prediction of particle-laden turbulent jet flows is important for the understanding of the mechanism of particles transport by turbulence [2].
The relevant control parameter which drives the particles dynamics is the Stokes number, defined as the ratio between the particle relaxation time and the characteristic flow time scale. For small Stokes number, i.e. $St \ll 1$, the particles inertia is small and the disperse phase follows exactly the fluid trajectory (tracer limit). At very high Stokes number, i.e. $St \gg 1$, the particle inertia is predominant and the ballistic regime is achieved. For intermediate Stokes number the particle dynamics and the ensuing spatial distribution strongly depend on their inertia. In fact, in turbulent flows particles tend to filter out rapid fluid velocity fluctuations and to follow only the slow fluctuations. This transitional regime is subtle since also light particles preserve a memory of their initial condition at the jet inlet [3]. The present contribution concerns the one to one comparison of a turbulent round jet fed with an actual turbulent pipe flow. In fact, at a comparable value of the Reynolds number of $1.6 \cdot 10^4$, the same particle population can be followed and the ensuing statistics can be compared both for the fluid and the disperse phase.

EXPERIMENTAL AND NUMERICAL SETUP: RESULTS AND DISCUSSION

The experimental apparatus allows the investigation of a fully turbulent jet by means of Particle Image Velocimetry (PIV). The experiments are carried out in the labs of the Department of Mechanical and Aerospace Engineering of the University of Rome La Sapienza. The set-up consists of a cylindrical stagnation chamber connected to a high pressure circuit and a seeding system for PIV. The chamber is equipped with a pressure sensor. The cylindrical test chamber has two windows for optical access and is connected to the stagnation ambient by means of a circular pipe. The pipe, diameter $D = 6\,mm$ and length $L = 70\,cm$, i.e. $L = 116\,D$, allows to obtain a fully developed flow at the outlet in agreement with what reported in the available literature, see e.g. [5]. The PIV system consists of a double-pulse Nd:YAG Quantel laser with maximum energy per pulse of $200\,mJ$, a pulse duration of $5\,ns$ and a repetition frequency of $5\,Hz$. The interval between the two laser pulses is set to $12\,\mu s$ to obtain a maximum particle displacement of 15 pixels. A PCO Pixelfly Usb camera is used to acquire pair of images with resolution of 1340 x 1024 pixels and a dynamic range A/D of 14 bit. The spatial resolution of 35 pixels/mm is obtained. PIV image processing is performed by La Vision Davis software on 5000 pairs of images for each investigated condition using a multi pass algorithm with an overlap factor of 75%. The flow is seeded in the stagnation chamber with olive oil droplets of diameter $d = 5\,\mu m$ by means of a Laskin nozzle generator. The jet is operated at a bulk velocity of $40\,m/s$ which achieves a Reynolds number of about $Re = 16000$ based on the pipe diameter D. In such conditions the seeding droplets have a Stokes number of $St \simeq 1$.
The DNS is carried out by an in-house developed code [4] which solves the Navier-Stokes equations in cylindrical co-ordinates. The round jet is fed by an actual turbulent inlet achieved via a companion DNS of a turbulent pipe flow. At each time-step the turbulent flow sampled in a section of the pipe is used to prescribe a physically accurate inlet for the jet. The code allows the simultaneous tracking of point-like particles which can be injected at the jet inlet either uniformly or in the uneven distribution ensuing from the previous evolution experienced in the pipe flow. This strategy allows a one to one comparison with the experimental setup where the particles are injected in the stagnation chamber and successively feed the jet after their evolution through the inlet pipe. The equation are discretized in a cylindrical domain–whose azimuthal, radial and axial dimensions are $[2\pi \otimes 72 \otimes 100]R$, respectively–with about $3 \cdot 10^8$ collocation points, $[N_\phi \otimes N_r \otimes N_z] = [384 \otimes 433 \otimes 1792]$. The grid is stretched in the radial and axial directions to achieve an

accurate resolution. Indeed, a fine resolution is needed because of the relatively high Reynolds number and because of the large dimensions of the integration domain.

The particle instantaneous field is provided in figure 1 both for the experimental (left black/white panel) and for the DNS case (right black/white panel). In the talk, a more detailed comparison of the particle spatial distribution will be presented in terms of the mean particle concentration field and of centerline distribution which is known to be sensitive to the initial condition at the inlet, see e.g. [3].

The color contour plots in figure 1 present the instantaneous fluid velocity sampled by the particles in the experiments and the Eulerian fluid velocity obtained by the DNS simulation. It is known that particles with relatively low inertia might not be adequate to sample all the velocity fluctuations or the velocity gradients. The talk will address this issue in more detail by comparing low order statistics as the mean fluid velocity profile and progressively higher order statistics such as the variances of the velocity fluctuations and the different terms arising in the turbulent kinetic energy budget of the round jet.

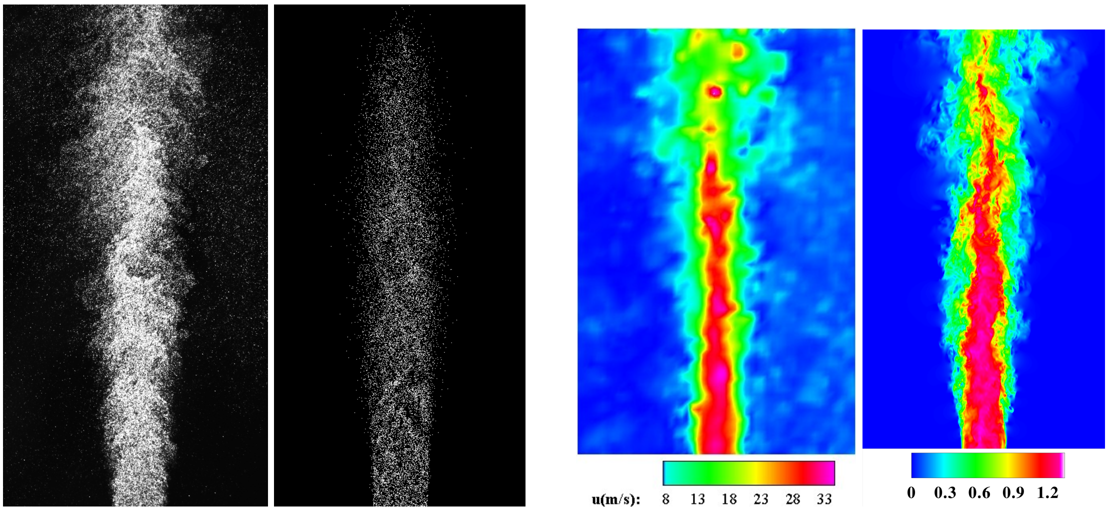

Figure 1. Left panel pair (black/white). Instantaneous particle configuration in the experiments (left) and in the DNS (right) at comparable Reynolds number of $Re = 16000$ and $St \simeq 1$. Right panel pair (contour plot): instantaneous fluid axial velocity as sampled by the particles in the experiment (left panel) and Eulerian axial velocity ensuing from the DNS data.

References

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