Lagrangian compressible dynamics in a self-similar incompressible jet

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A large-scale experimental Lagrangian study based on *Particle Tracking Velocimetry* (PTV) has been completed in an incompressible turbulent round water jet freely spreading into water with a Taylor-based Reynolds number $Re_\lambda \simeq 230$. The vertical jet is ejected from a round nozzle with a diameter $D = 4$ mm and the measurement volume spans 80 mm $= 20D$ in the self-similar region. The jet is seeded with neutrally buoyant spherical polystyrene tracers with a diameter of 250 microns. The particularity of this study is that the jet is seeded only through the nozzle (inhomogeneous seeding called *nozzle seeding*). The Lagrangian flow of tracers therefore does not contain any contribution from particles entrained into the jet from the surrounding fluid. Tracers are tracked with three high speed cameras at 6000 fps, then PTV methods are used to obtain tracer trajectories. New calibration [1] and matching [2] algorithms are especially used.

We will report here results on the mean velocity field $\boldsymbol{U_\varphi}$ of tracked particles which we compare to the well-known self-similar velocity field $\boldsymbol{U}$ of the jet [3]. We show that $\boldsymbol{U_\varphi}$ is essentially undistinguishable from $\boldsymbol{U}$ for the axial velocity while important discrepancies are found for the radial velocity. These discrepancies are interpreted and analysed by considering the flow of particles as effectively compressible. Indeed, as particles entrained into the jet are not tracked, even if the jet flow is incompressible ($\boldsymbol{\nabla} \cdot \boldsymbol{U} = 0$), the *nozzle seeded* flow is not divergence-free ($\boldsymbol{\nabla} \cdot \boldsymbol{U_\varphi} \neq 0$). To account for this apparent compressibility, a new mass conservation equation is proposed by considering the mean tracer density field φ: $\boldsymbol{\nabla} \cdot (\varphi \, \boldsymbol{U_\varphi}) = 0$. This model can be solved analytically and successfully describes the experimental radial velocity field, emphasizing the specific role of entrainment up to the core of the jet.

Finally, we reinterpret this effectively compressible dynamics in terms of a simple diffusion process linking $\boldsymbol{U}$ with φ through a classical advection-diffusion equation: $\boldsymbol{\nabla} \cdot (\varphi \, \boldsymbol{U} - K_T \boldsymbol{\nabla} \varphi) = 0$, with K_T an eventually spatial-dependent turbulent diffusion coefficient for the tracers. We theoretically and experimentally determine the radial-dependent coefficient $K_T(r)$, which can be linked with known turbulent viscosity $\nu_T(r)$ through turbulent Prandtl number $\sigma_T(r)$ determined as well.

This study, which combines Lagrangian approach with turbulent scalar transport, gives new experimental and theoretical elements for a better comprehension of turbulent diffusion and of the role of entrainment in a turbulent jet.

References

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