Abstract

This thesis investigates the physics of statistically unsteady axisymmetric turbulent jets and plumes using theory and direct numerical simulation. The focus is on understanding and modelling the physics that govern the behaviour of radially integrated quantities, such as the integral scalar flux, momentum flux and buoyancy flux. To this end, a framework is developed that generalises previous approaches, making no assumption about the longitudinal velocity profile, turbulence transport or pressure. The framework is used to develop well-posed integral models that exhibit a good agreement with simulation data. In the case of passive scalar transport, shear-flow dispersion is observed to be dominant in comparison with longitudinal turbulent mixing. A dispersion closure for free-shear flows based on the classical work of Taylor (*Proc. R. Soc. Lond.* A, vol. 219 1954*b*, pp. 186-203) is therefore developed. In the analysis of jets whose source momentum flux undergoes an instantaneous step change, it is demonstrated that a momentum–energy framework, of the kind used by Priestley & Ball (*Q. J. R. Meteorol. Soc.*, vol. 81 1955, pp. 144-157), is the natural choice for unsteady free-shear flows. The framework is used to demonstrate why existing top-hat models of unsteady jets and plumes are ill-posed and that jets and plumes with Gaussian velocity profiles remain approximately straight-sided and are insensitive to source perturbations. Contrary to the view that the unsteady jet and plume equations are parabolic, it is shown that the generalised system of equations is hyperbolic. In unsteady plumes, the relative orientation of three independent families of characteristic curves determines whether propagating waves are lazy, forced or pure. To relate findings that are based on the momentum–energy framework to the classical mass–momentum framework, an unsteady entrainment coefficient is defined that generalises the decomposition proposed by Kaminski *et al.* (2005, *J. Fluid Mech.*, vol. 526, pp. 361-376).