SELF-SIMILARITY OF PASSIVE SCALARS IN A DECELERATING JET

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ABSTRACT

Scalar mixing is investigated in a decelerating turbulent round jet using direct numerical simulation with Reynolds number 7 290. The mass fraction of jet fluid and the fluid residence time, measured by the mass-weighted age of the jet fluid, both exhibit self-similar radial profiles in statistically-stationary turbulent jets. Upon stopping the inflow, a deceleration wave passes through the jet, as illustrated in Fig. 1. Behind the deceleration wave a new self-similar state is observed for the two scalar variables. The self-similar profiles of the averaged scalar variables differ between the steady-state and decelerating jets, however the differences are relatively small and it might be a reasonable approximation to use radial profiles from steady-state jets in some modelling applications. The assumption of transient self-similarity of the scalar fields in the decelerating jet leads to theoretical predictions concerning the form of the turbulent scalar fluxes, and these predictions are consistent with the simulation data – providing further evidence for self-similarity of the scalar fields in the decelerating jet.

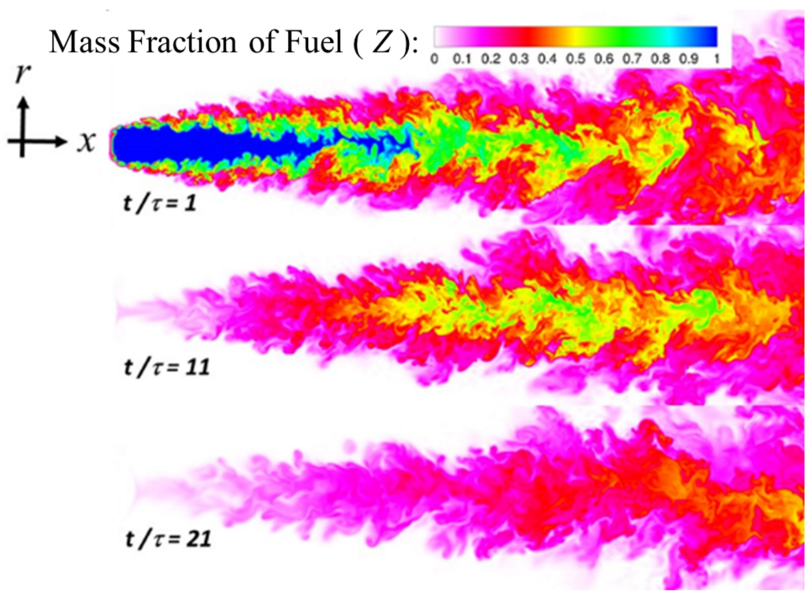

Figure 1. Cross-sectional colour maps of the instantaneous jet fluid mass fraction following stopping of the jet at $t/\tau = 0$.

Behind the deceleration wave the jet fluid mass fraction exhibits a linear increase with downstream distance, opposite to the mass fraction dependence in the steady-state jet. In contrast, the centreline profile of mass-weighted stream age remains proportional to downstream distance, with a slight change of the gradient, and becomes independent of time. The transport budgets for the averaged jet fluid mass fraction and mass-weighted stream age show marked differences in the decelerating jet, compared to the steady-state jet. In particular the entrainment is around three times greater in the decelerating jet, promoting the importance of radial convection. Remarkably, the unsteady term is negligible in the mass-weighted stream age budget in the decelerating jet, so that the averaged mass-weighted stream age distribution returns to a statistically stationary state after the deceleration wave has passed, even though the flow continues to decelerate.