The turbulent/non-turbulent interface in a plume

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Abstract

We present measurements of the scalar and velocity fields of turbulent plumes at high Reynolds and Peclet numbers. We describe how measurements of the movement of identifiable features at the edge of a turbulent plume can be interpreted to determine the properties of the mean flow and consequently, using plume theory, can be used to make estimates of the fluxes of volume (mass), momentum and buoyancy in a plume. This means that video recordings of smoke rising from a chimney or buoyant material from a source on the sea bed can be used to make accurate estimates of the source conditions of the plume. At best we can estimate the volume flux and buoyancy flux to within about 5% and 15% of the actual values, respectively. In addition, we demonstrate that large scale coherent structures at the plume edge form on a scale approximately 40% of the local plume half-width and travel at almost 60% of the average local velocity in the plume.

Particle image velocimetry measurements with simultaneously detection of the scalar edge of a plume demonstrate the significance of engulfment within the process of turbulent entrainment. We show that the vertical mass transport, induced by the plume, within the irrotational ambient environment is a significant portion of the vertical mass transport. This vertical mass transport within the ambient typically occurs in the vertical space between turbulent coherent structures which form at, and are advected along, the plume edge. In such regions, the vertical mass transport outside the plume is approximately 40% of the total mass transport. The vertical momentum imparted on these pockets of ambient fluid enable it to be easily engulfed into the plume.

We argue that turbulent entrainment is initiated by the engulfment of (relatively high momentum) ambient fluid which occurs at the largest scales within the plume. This engulfed fluid is then stretched, and vorticity imparted, at the plume edge; after which, at far smaller scales, irreversible molecular mixing takes place. Hence, unlike a number of studies which conclude 'nibbling' at the interface dominates entrainment, we argue that engulfment should be viewed as the initial stage of the process of turbulent entrainment by plumes. As such, engulfment constitutes a significant, indeed vital, part of turbulent entrainment. These new insights shed light on the process of turbulent entrainment in plumes – insights which we believe hold relevance for the process of turbulent entrainment in other canonical free-shear flows.

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