BUDGETS OF TURBULENT KINETIC ENERGY AND SCALAR VARIANCE IN THE SELF-SIMILAR REGION OF A ROUND JET

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Abstract The budgets of turbulent kinetic energy and variance of passive scalar fluctuations are presented in the self similar region of a fully developped turbulent round jet. LDV and cold-wire thermometry were simultaneously used to determined these budgets in the same flow conditions. It is shown that scalar dissipation reaches self preservation at $x/D = 25$ and scales as x^{-4} with a constant $K_{\epsilon_\theta} = 14.9$.

INTRODUCTION

The dissipation of kinetic energy and passive scalar fluctuations is an important quantity for the calculation of small scale structure dimensions in the centerline of a turbulent jet. For small scale self similarity studies, Taylor and Kolmogorov length scales are used in the normalization of velocity and temperature spectra. For temperature (passive scalar) dissipation measurements, Kolmogorov length scale is required for correct measurements. For the kinetic energy, the observation of Landau and Lifshitz [6] led Friehe et al. [5] to suggest a relationship for a round jet in the self-similar for the mean rate of viscous dissipation of kinetic energy ($\epsilon = C\ U_0^3/R_U$). They suggested a semi-empirical expression for kinetic energy dissipation that they validate with data from the literature. The expression was latter verified by Antonia et al. [2] and is widely adopted in the literature for round jet studies ([4]). Similarly to the kinetic energy evolution along the jet centerline axis, temperature dissipation, when normalised by local characteristics of the jet on the centerline, can be written as $\epsilon_\theta = C'\ U_0\Theta_0^2/R_U$. This leads to ϵ_θ decaying with x^{-4}. Antonia and Mi [1] found C' to be equal to 0.0095, while Ruffin et al. [8] found 0.013 for a confined jet issuing from a tube. The validity of this relationship and the value of C' did not receive as much attention as the one of kinetic energy dissipation.

In this study a free round jet operating at a high Reynolds number ($\mathrm{Re_D} = 1.5 \times 10^5$). The jet is slightly heated and temperature is considered as a passive scalar. The dynamic and passive scalar fields were measured simultaneously in the self similar of the jet and along the jet centerline. LDA and cold-wire thermometry were used simultaneously to measure with high accuracy the velocity temperature correlations. The mean characteristics of the jet were first determined and important parameters that characterize the initial conditions were calculated and discussed.

BUDGETS OF k AND $\overline{\theta^2}/2$

Budgets of kinetic energy and scalar variance were both determined (Figure 1) in the same flow conditions at $x/D = 30$. They show interesting features not observed by previous experimental works. Kinetic energy production matches the LES simulation of Bogey and Bailly [3], particularly around the jet centerline. Dissipation is also well deduced considering the good match with the data reported by Panchapakesan and Lumley [7] and with the reminder of Bogey and Bailly [3] which contains the extra term of pressure velocity correlation that, according to their simulation, is small but not negligible around the jet centerline. For the budget of temperature variance, the data presented complement the results of Antonia and Mi [1] who obtained the dissipation term from direct measurements. In their case, turbulent diffusion was inferred from the budget remainder. In the present case, however, the dissipation has been inferred from the budget remainder and diffusion was directly measured. On the jet axis, the present estimate of ϵ_θ deduced from the budget is observed to be in very good agreement with a direct measurement obtained from local isotropy and Taylor's hypothesis. Here, $\epsilon_\theta R_U/(U_0\Theta_0^2) = 0.0095 = C'$ at $\xi = 0$. Local isotropy on the jet axis was also observed by Antonia and Mi [1].

SMALL-SCALE SIMILARITY

Using local characteristic scales and measurements along the jet axis (Figure 2), it is shown that the normalised evolution of rms velocity and temperature fluctuations reach equilibrium at $x/D = 20$. The evolution of normalised dissipation along the jet centerline obtained using local isotropy shows equilibrium for small scales further downstream, at $x/D = 26$. Given that R_U scales with x, U_0 and Θ_0 both scale with x^{-1}, this lead to an x^{-4} dependency of ϵ_θ. Using global parameters for normalisation, on can thus write:

$$\frac{\epsilon_\theta D}{U_j\Theta_j^2} = K_{\epsilon_\theta}\left(\frac{x - x_0}{D}\right)^{-4} \quad \text{with } K_{\epsilon_\theta} \simeq 14.9$$

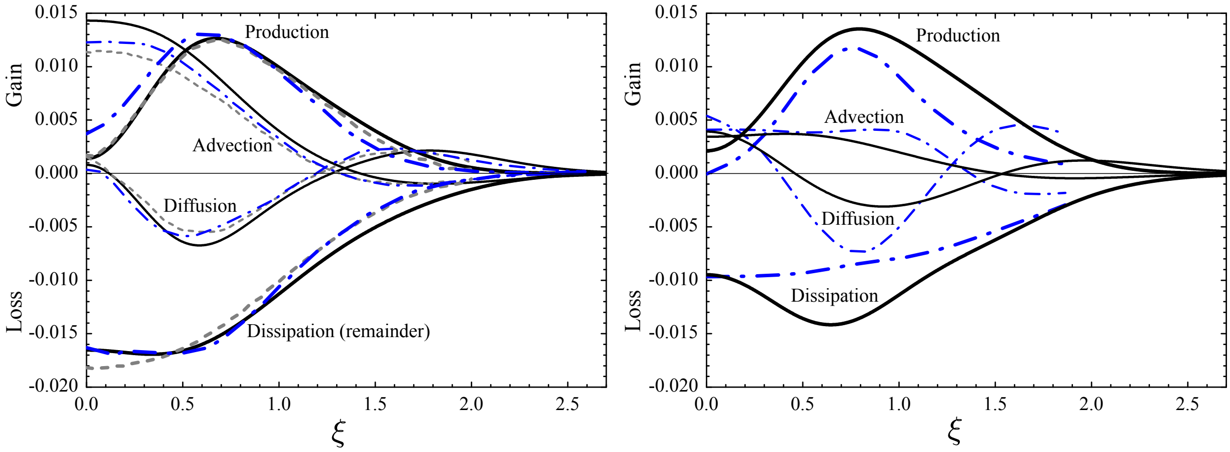

Figure 1. Budgets of turbulent kinetic energy (left) and half of temperature variance (right): solid line, present results; dash-dotted line, k budget of [7] and $\overline{\theta^2}/2$ budget of [1]; dashed line, k budget of [3].

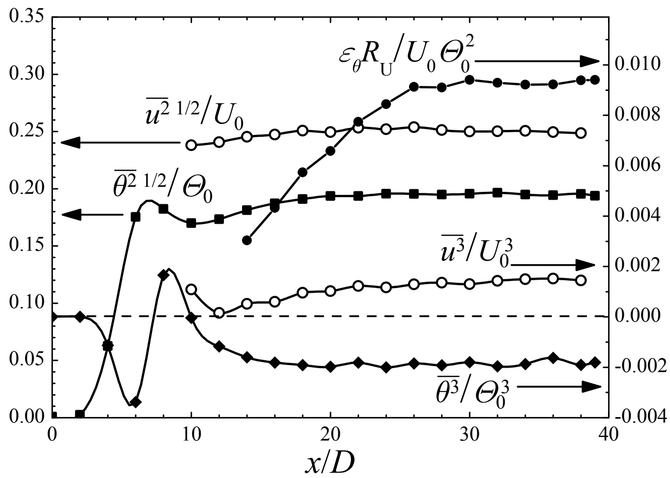

Figure 2. Axial distribution of centerline normalized values of $\sqrt{\overline{u^2}}$, $\overline{u^3}$, $\sqrt{\overline{\theta^2}}$, $\overline{\theta^3}$ and ϵ_θ.

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