Experimental study of an unsymmetrical wake of a passive scalar in a symmetrical dynamic wake

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Abstract The present study examines the development of a symmetrical dynamic plane wake with an asymmetric scalar contamination considered as passive. The plane wake is generated by two identical flat plates located side-by-side across the test section of a wind tunnel. The original aspect of this study is that one flat plate is heated 20 °C above the ambient and the other is cooled 20 °C below the ambient. An antisymmetric thermal wake (zero net thermal injection) is thus generated. Simultaneous hot-wire anemometry/cold-wire thermometry measurements are conducted to evaluate turbulent kinetic energy and temperature variance budgets in identical flow conditions. The development of the wake and the grade of self-preservation in the intermediate wake are investigated and areas of local similarity are identified. The budgets for the turbulent kinetic energy and the temperature variance are established. The dissipation rates of turbulent kinetic energy and temperature fluctuations are inferred as the closing balance of the two budgets.
Keywords: Plane wake, Passive scalar, Turbulence

1 Introduction

The study of mass and heat transfer in atmospheric flows are of extreme importance considering the historical evolution of energy sources and pollution problems. Complex flow configurations occurring in nature or industry make the problem particularly difficult. The challenging question of how to accurately predict the features of a scalar transported by a given velocity field is of particular interest. The transported scalar can either be passive, without interfering with the velocity field, or active (due to chemical reaction or a significant buoyancy force). This study examines the development of a symmetrical dynamic wake with an asymmetric scalar contamination considered as passive. If theoretical and numerical modelling of complex flows is to be realized, reliable data for simpler classical flows are needed as benchmarks. In that sense, experimental study of the evolution of a slightly heated plane wake can offer unique insight into the finest of turbulent motions, together with an opportunity for quantitative assessment of passive scalar mixing.

2 Experimental setup and measurement techniques

A plane wake is generated by two identical flat plates located side-by-side across the test section of a wind tunnel (Fig. 1). This results in a symmetric dynamic wake composed of the two flat plate wakes evolving side by side and eventually merging further downstream at a given distance. The original aspect of this study is that one flat plate is heated 20 °C above the ambient and the other is cooled 20 °C below the ambient. An antisymmetric thermal wake (zero net thermal injection) is thus generated. The free stream velocity is set to 25.6 m/s, resulting in a Reynolds number based on the momentum thickness in the far wake of about 10 000.

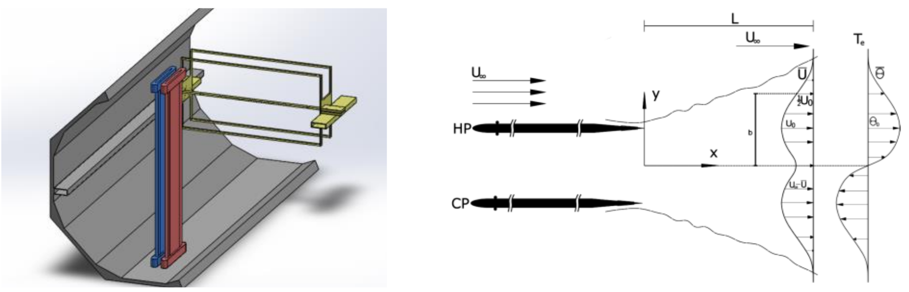

Fig. 1 Experimental setup. On the left side, hot (red) and cold (blue) plates mounted in the wind tunnel and traversing mechanism (yellow) located downstream; on the right side, sketch of the dynamic and scalar wakes.

Simultaneous hot-wire anemometry/cold-wire thermometry measurements are conducted to evaluate turbulent kinetic energy $k = \frac{1}{2}\left(\overline{u^2} + \overline{v^2} + \overline{w^2}\right)$ and temperature variance $\overline{\theta^2}/2$ budgets in identical flow conditions. Neglecting molecular diffusion (high Re assumption), k and $\overline{\theta^2}/2$ budgets (with the pressure-diffusion term Π_k estimated using Lumley's model) are respectively written as follows:

$$0 = \underbrace{-\left[\bar{U}\frac{\partial k}{\partial x} + \bar{V}\frac{\partial k}{\partial y}\right]}_{Advection\ C_k} \underbrace{-\left[\overline{u^2}\frac{\partial \bar{U}}{\partial x} + \overline{v^2}\frac{\partial \bar{V}}{\partial y} + \overline{uv}\left(\frac{\partial \bar{U}}{\partial y} + \frac{\partial \bar{V}}{\partial x}\right)\right]}_{Production\ P_k} \underbrace{-\frac{1}{2}\left[\frac{\partial\left(\overline{u^3}+\overline{uv^2}+\overline{uw^2}\right)}{\partial x} + \frac{\partial\left(\overline{u^2v}+\overline{v^3}+\overline{vw^2}\right)}{\partial y}\right]}_{Turbulent\ diffusion\ D_k} + \Pi_k - \epsilon_k \quad (1)$$

$$0 = \underbrace{-\left[\bar{U}\frac{\partial(\overline{\theta^2}/2)}{\partial x} + \bar{V}\frac{\partial(\overline{\theta^2}/2)}{\partial y}\right]}_{Advection\ C_\theta} \underbrace{-\left[\overline{u\theta}\frac{\partial \bar{\Theta}}{\partial x} + \overline{v\theta}\frac{\partial \bar{\Theta}}{\partial y}\right]}_{Production\ P_\theta} \underbrace{-\frac{1}{2}\left[\frac{\partial \overline{u\theta^2}}{\partial x} + \frac{\partial \overline{v\theta^2}}{\partial y}\right]}_{Turbulent\ diffusion\ D_\theta} - \epsilon_\theta \quad (2)$$

3 Results

The profiles of mean velocity $\bar{U}$ and temperature difference $\bar{\Theta}$ are respectively shown in Fig. 2 and the budgets are presented in Fig. 3 for the inner and outer regions of the wake at $x = 800$ mm ($x/\delta_2 = 135$), where δ_2 is the momentum thickness at this location.

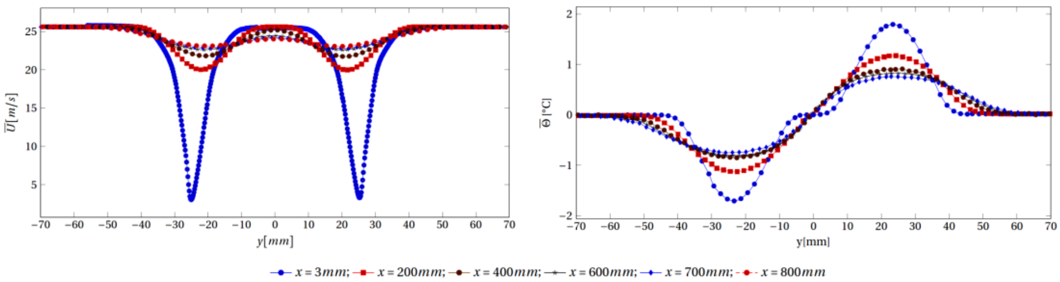

Fig. 2 Mean longitudinal velocity (left) and temperature (right) profiles at different streamwise locations x.

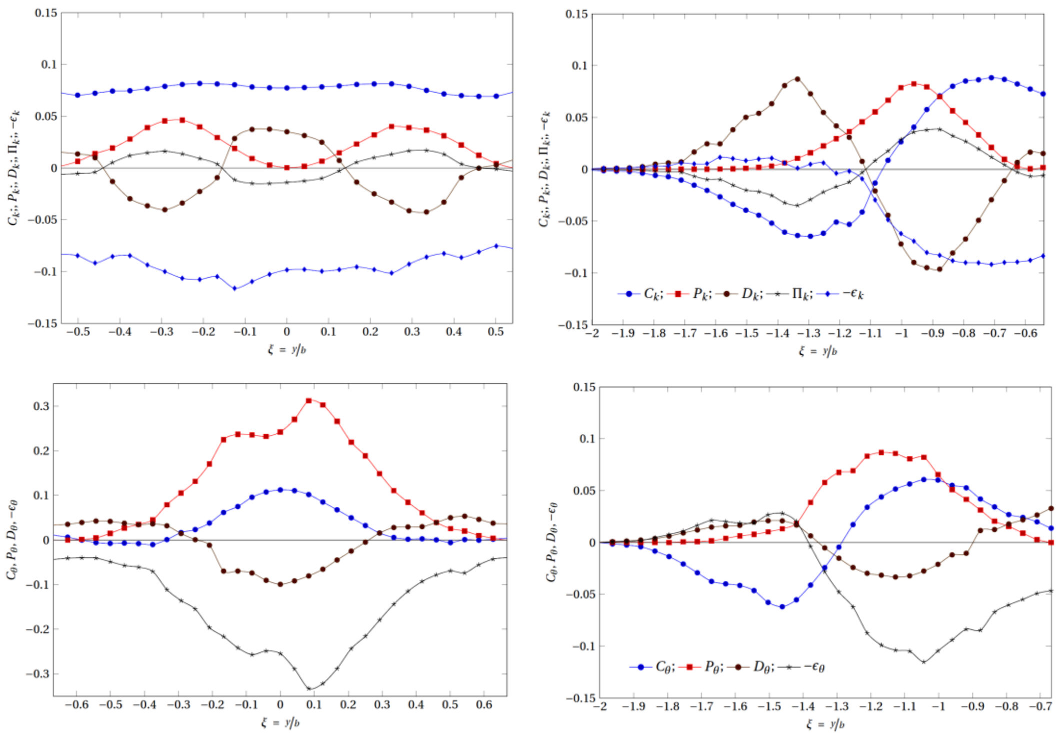

Fig. 3 Budgets of k (top) and $\overline{\theta^2}/2$ (bottom) for the inner (left) and outer (right) wake measured at the streamwise location $x = 800$ mm ($x/\delta_2 = 135$); the dissipation terms ϵ_k and ϵ_θ are inferred as the closing balance.