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Simultaneous two-dimensional determination of mixture fraction and flow velocity in a non-reacting free jet flow by planar LIF and PIV

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In this study we present an experimental approach for the simultaneous two-dimensional measurement of mixture fraction and flow velocity in non-reacting jet flows by the simultaneous application of planar laser-induced fluorescence (LIF) and particle image velocimetry (PIV). The aim of this work is to provide data for the validation of models used in Large Eddy Simulations (LES) which require measurement both at filtered and on sub-grid levels. Therefore, a high spatial resolution for both measurement techniques is adjusted.

Beside the experimental challenge to measure the two-dimensional flow field of large velocities (Ma$\approx$0.2) in small regions of interest with a distance between adjacent vectors of almost 100 µm, a quantitative measurement technique for the simultaneous determination of the mixture fraction *f* is developed. In the context of this study with an inner jet flow and a surrounding co-flow, the mixture fraction *f* is defined in terms of the maximum concentration of the

$$f = \frac{y_i}{y_{i,0}} \qquad (1)$$

inner flow $y_{i,0}$ (1).

A gaseous fluorescence tracer is added to the central flow in order to measure the mixture fraction directly from the number-density dependent laser-induced fluorescence signal. The tracer is chosen to have a similar molecular mass as the carrier flow so that diffusivity effects of the tracer out of the traced flow could be neglected. Different post processing steps were combined in order to exclude influences like temporal and spatial fluctuation of the laser intensity which could have a negative effect on the quantitative evaluation.

The simultaneous measurement of the mixture fraction and the flow field with high resolution allows to acquire appropriate data sets for comparisons with LES. Therefore, by spatially averaging some adjacent regions of interest (see Fig. 1), the investigated quantities

$$\overline{u_i} = \frac{1}{n}\sum_{j=1}^{n} u_{i,j} \qquad \overline{f} = \frac{1}{n}\sum_{j=1}^{n} f_j \qquad \overline{u_i f} = \frac{1}{n}\sum_{j=1}^{n} u_{i,j}\cdot f_j$$

can be evaluated both above the filter size Δ, which presents the final resolved scales in the LES codes, and below the filter size, where models are used to describe the transport mechanisms.

This enables to measure directly the so called subgrid scale (SGS) scalar flux $J_i^{sgs} = -\left(\overline{u_i f} - \overline{u_i}\cdot\overline{f}\right)$, which is usually modelled with standard gradient approaches in conjunction with the Smagorinsky-model for the subgrid scale turbulent viscosity ν_t:

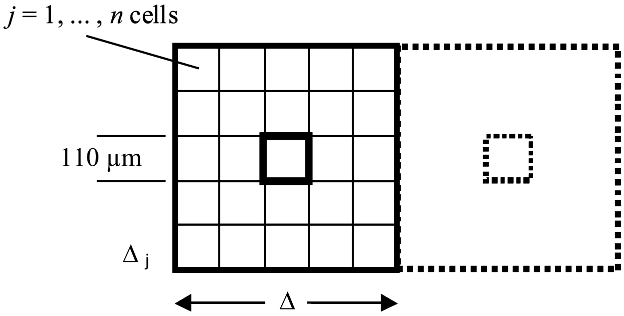

Fig. 1 Spatial averaging of directly measured sub-scale quantities

$$J_i^{sgs} = \frac{\nu_t}{\sigma_t}\frac{\partial \overline{f}}{\partial x_i}. \qquad (2)$$

Exemplary, measured data are presented for a non-reacting jet-flow for a Reynolds number of 31714. The applied experimental set-up consisted of a central nozzle from where air is expanded isothermally with high outlet velocities into a slowly moving co-flow. Radial profiles at three different downstream positions have been investigated, whereas one is located as close as possible at the rim of the central nozzle in order to provide inlet conditions for numerical simulations.

An image of the simultaneously obtained flow and mixture fraction field is depicted in Figure 2. In this, every second vector is presented for clarity, with the mixture fraction increasing from blue to red.

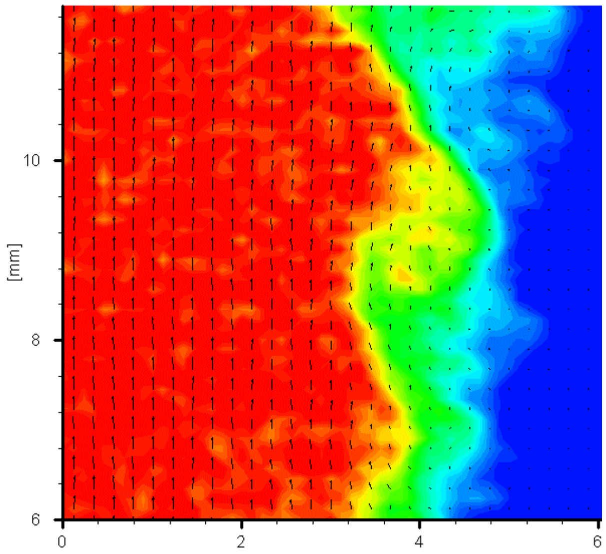

Fig. 2 False colour representation of the measured mixture fraction (simultaneous velocity vectors superposed)