HIGHER ORDER MOMENTS OF PASSIVE AND REACTING SCALARS AND THEIR GRADIENTS IN TURBULENT WALL-JETS

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Abstract The concept of local isotropy [1,2] of passive and active scalar fields is addressed for a turbulent wall-jet. A plane wall-jet is formed when a jet flow is injected parallel and next to a solid surface. At the inlet of the computational domain, both a fuel component (active) and a passive scalar are injected through the jet stream, within the height h [3]. The mean profiles of the two scalars are shown in Fig. 1. The remainder of the inlet consists of a coflow with a velocity of the order of 10% of the jet flow and contains 50% of the oxidizer. The reaction forms in such a way that a considerable amount of fuel is consumed throughout the domain. The main objective of this study is to use the DNS-database to address the statistical characteristics of both active and passive scalars. In particular, we discuss the properties of skewness and flatness at large and small scales. The scalar statistics are interesting both for applied problems, when the large scale properties such as the scalar variance and the scalar flux are examined, and for fundamental ones, concerning the universal properties of the advected fields.

SKEWNESS AND FLATNESS FACTORS OF SCALARS

In order to investigate the statistical properties of both active and passive fields at different wall-normal levels, the skewness and flatness of the scalar fluctuations are shown in Figs. 2. From studying the skewness factor of the scalar and of its gradient, one can quantify the large-scale and the small-scale degree of anisotropy of the fields [4,5]. Note that, the skewness of the scalar fluctuations is connected to the large-scale anisotropy and the skewness of the scalar gradients to the small scale anisotropy. At the wall, both scalars show a negative skewness factor, but the reacting scalar gradually deviates from the passive scalar getting to larger and larger skewness values when the combustion becomes more and more active far from the wall. As one can see from Fig. 1a, most of the reaction happens for $0.5 < y/y_{1/2} < 1.5$, as indicated by the fact that the passive and the active scalars develop two very different profiles in this range. As seen in Fig. 2a the passive scalar is always close to a Gaussian at large scales, with a skewness close to zero and a flatness close to 3, except for the region very close to the wall. On the other hand, the fuel starts to deviate from a Gaussian distribution when it becomes active, as shown by the increasing of the flatness values (Fig. 2b) and the developing of a non-zero skewness (Fig. 2a), in the region $y/y_{1/2} > 0.5 - 0.8$ where the reaction becomes intense.

SKEWNESS AND FLATNESS FACTORS OF GRADIENTS

The skewness and flatness factor of the scalar gradients in the wall-normal direction are shown in Fig. 3. Let us stress that in a purely isotropic case, all odd moments of the gradients are exactly vanishing, so a measure of the skewness of $d\theta/dy$ gives a direct quantitative information on the degree of anisotropy. The skewness of the passive scalar gradient, $Sk_{d\theta/dy}$ crosses zero close to $y/y_{1/2} = 0.75$, where also the flatness profiles of passive and reacting scalars cross each other. The skewness of the gradients for both fields show negative values at the wall and for a wide region above the wall $0.2 < y/y_{1/2} < 1.0$, there is a plateau with a negative value about -1.2, indicating a strong small-scale universal anisotropy. Here for universality we mean independent of the large-scale properties of the flows. Going to a larger distance from the wall $y/y_{1/2} > 0.75$, the two fields start to have a different statistics also at small scales. The high values for the flatness of the fuel gradient is a further indication of a stronger non-Gaussian characteristics of the statistics at small-scales, induced by the reaction.

In a future investigation, we will also consider the exothermic reacting case, where we will address the heat-release effects on the PDF-shapes as well as higher order moments of different scalars.

References

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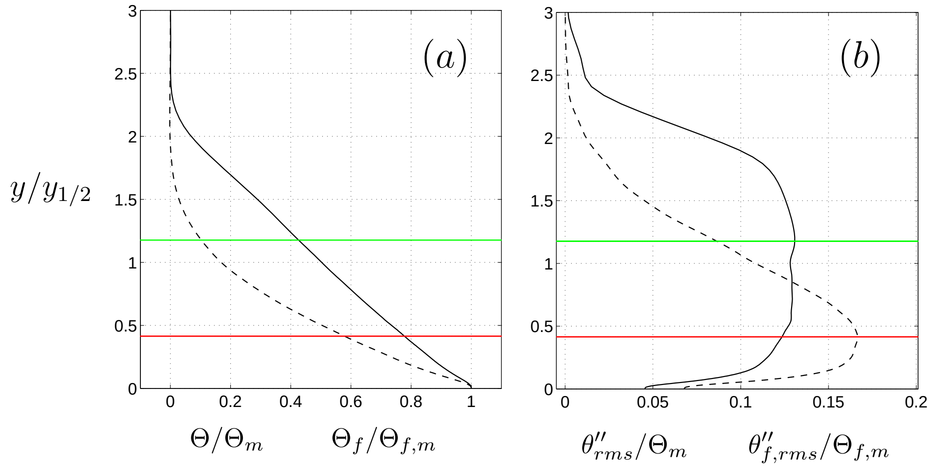

Figure 1. (a) Cross-stream profiles of the mean scalars and (b) the fluctuation intensities of scalars at $x/h = 25$; solid and dashed lines show passive and reacting scalars respectively. The red and green lines show the position of $\theta_{rms,max}$ and $\theta_{f,rms,max}$, respectively.

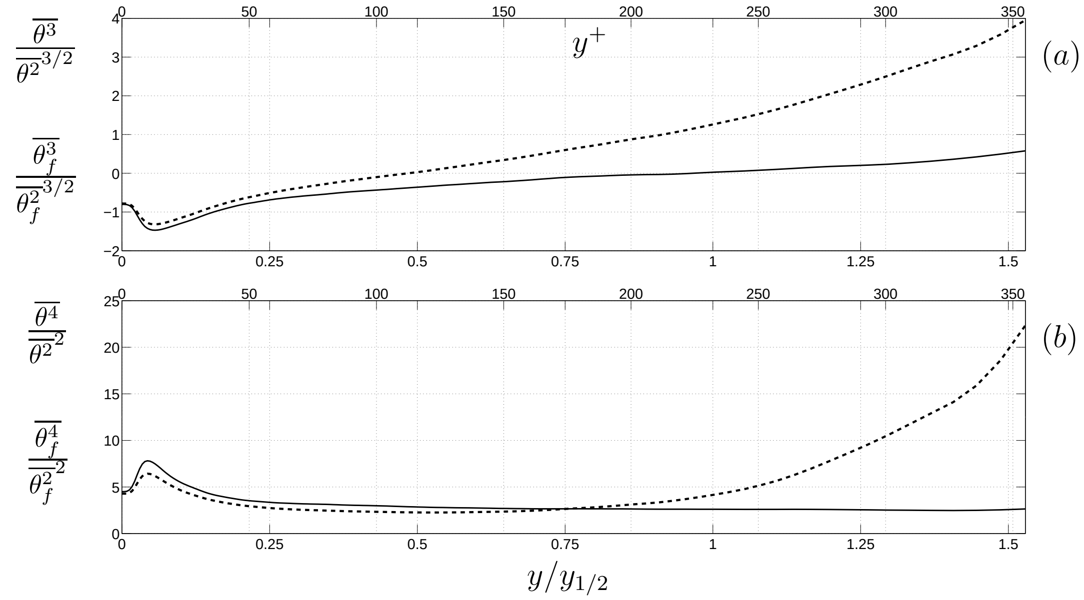

Figure 2. Distributions of third and forth-order moments, (a) skewness and (b) flatness of the scalar fluctuations at $x/h = 25$. Solid line: passive scalar and dashed line: fuel species. Here y^+ is yu_τ/ν and $y_{1/2}$ is the half-height of the jet.

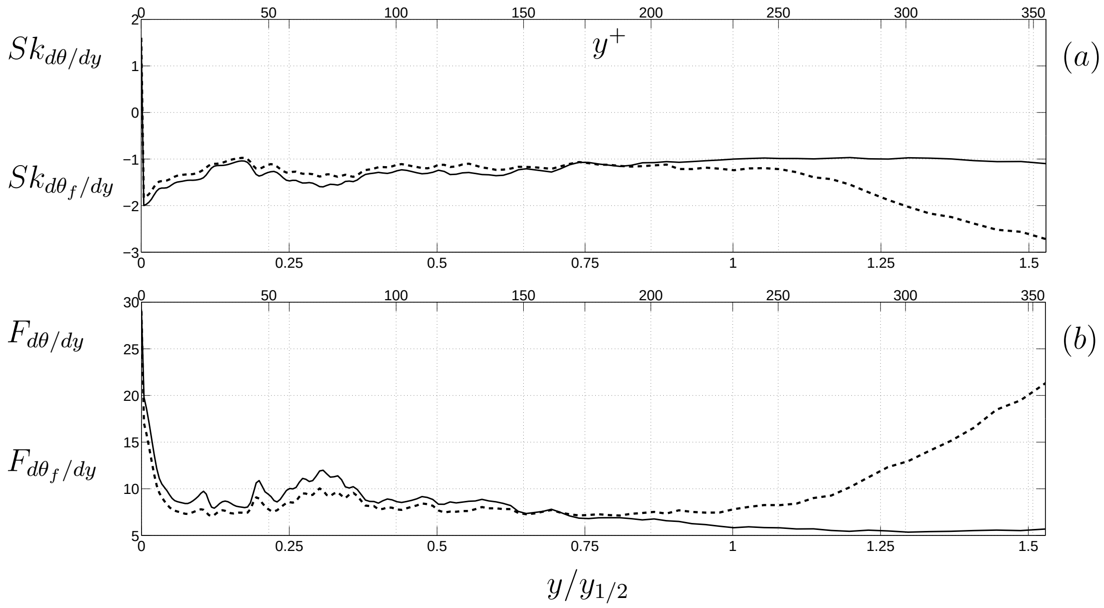

Figure 3. Distributions of (a) skewness and (b) flatness of the wall-normal gradients of the scalar fields, Line style as in Fig. 2.