Some thoughts on the meaningfulness of instantaneous heat transfer maps in turbulent flows

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Abstract This talk will present recent results of the author and co-authors measuring instantaneous convective heat transfer maps in turbulent flows. These measurements have been possible thanks to recent technological and processing developments which will be reviewed in the talk. Given this novel measurement tool is consequently important to identify what kind of information can be obtained about the physics of turbulent thermal transport.

The measurements are based on the use of IR thermography coupled with a quasi-steady heated-thin-foil heat transfer sensor. High-repetition-rate temperature measurements are employed to estimate the instantaneous maps of the convective heat transfer coefficient from the heated-thin-foil energy balance. Earlier measurements of this kind were performed by the group of Hetsroni, mostly in water, being those by Gurka et al. [1] a notable example. The large thermal inertia of heat transfer sensors typically inhibits high quality instantaneous heat transfer measurements in air. Following the seminal works by Nakamura's group [2-3] our group has initially developed phese averaged measurements [4] and later has developed feature-oriented filtering tools enabling high quality instantaneous heat transfer measurements despite the large thermal inertia of the sensor [5]. Proper Orthogonal Decomposition allows to minimize the measurement random noise, thus enabling the detection of small temperature fluctuations and, needed for the estimation of the convective heat transfer coefficient. An example of the result is reported in Figure 1.

The availability of instantaneous Nusselt number maps allow to provide a statistical characterization of the turbulent transport problem. In ref. [6] we have employed the instantaneous heat transfer maps for statistical modal analysis, providing insights on the mechanisms underlying turbulent transport in a boundary layer with ribs (see Fig. 2). A modal analysis employig both flow field and Nusselt number measurements allows to hipothesize a direct relation between the coherence of near-wall flow features and the heat-transfer augmentation, suggesting that near-wall coherent eddies are very efficient for heat transfer enhancement pourposes.

The availability of direct numerical simulation data has also allowed to perform modal analysis of composite velocity and temperature modes by means of the extended proper orthogonal decomposition [7]. Such analysis has shown to be extremely powerful since very few modes are sufficient to describe the turbulent thermal transport in a pipe. This pushes forward the need of synchronized flow field and convective heat transfer measurements. Complexities and challenges of such measurements will be also discussed.

Keywords: IR thermography, Convective heat transfer, POD

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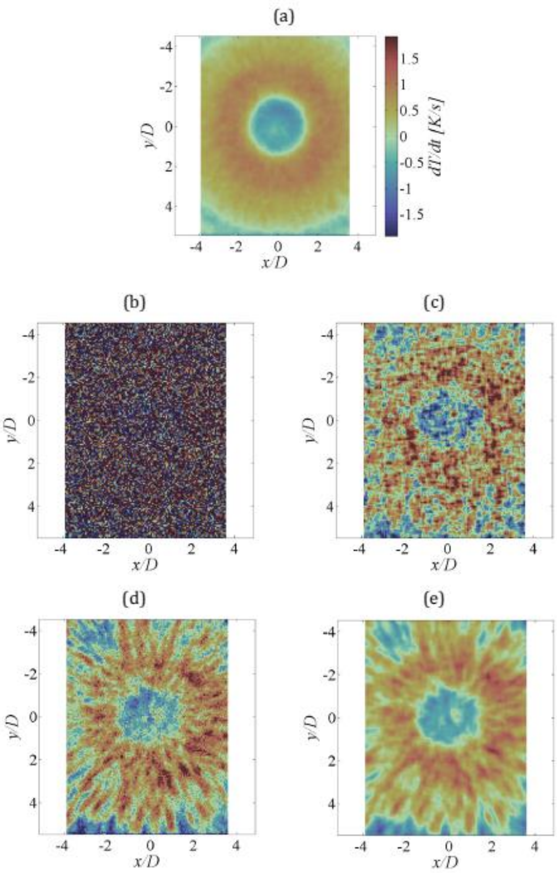

Fig. 1 Time derivative of temperature maps in a synthetic impinging jet (adapted from [5]): (a) phase average, (b) instantaneous raw, (c) instantaneous polynomial filter, (d) instantaneous POD filter, (e) instantaneous POD + polynomial filter. For the color scale refer to (a).

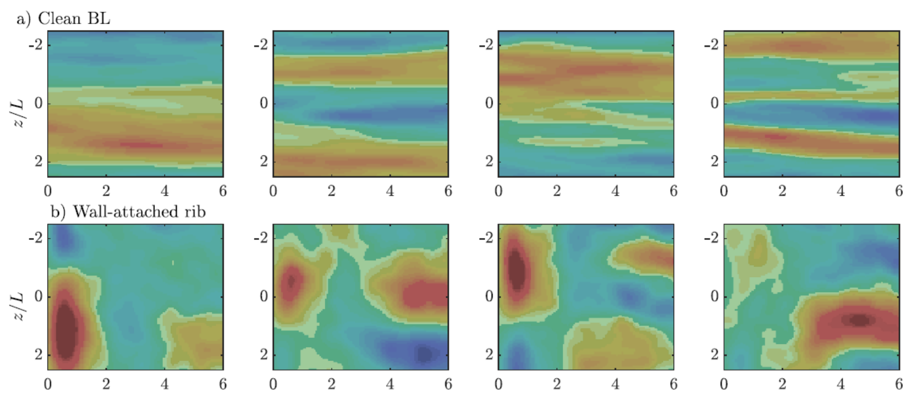

Fig.2 First four spatial modes of the unsteady convective heat transfer (Nu) obtained using POD for the (a) clean boundary layer, (b) wall-attached rib (adapted from [6])