On the suppression of PIV measurement noise with a POD based filter

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Random noise removal from PIV data is of paramount importance, especially for derivative quantities computation. Data filtering is critical, as a trade-off between filter effectiveness and spatial resolution penalty should be found. In this paper a filtering method based on POD low order reconstruction is proposed. It is demonstrated that the optimal choice of the number of modes to use in the reconstruction can allow for a minimization of random error. A criterion to perform this choice is also assessed. The method is validated via synthetic and real experiments, showing a substantial reduction of the measurement uncertainty as well as a significant improvement of the turbulent spectrum prediction.

Introduction

Experimental noise and spuriously detected vectors pose great challenges to the reliability of the measurement of gradient based quantities. One path to reduce the instantaneous measurement uncertainty consists in throwing information from the temporal to the spatial domain, such as in high speed PIV experiments (see Cierpka et al. 2013; Sciacchitano et al. 2012). In case of non-time-resolved data the chances to reduce the measurement uncertainty are very limited. In this work an approach based on the extraction of a statistical filter from velocity data ensembles is proposed using a POD-based low order reconstruction.

Results and discussion

The POD decomposes a flow field in an energetically optimal base. As the eigenvalues are ordered by their energy contribution it is possible to reconstruct the field using just the first \( k \) eigenmodes. It is possible to demonstrate that this reconstruction has a minimum error \( \delta_{kT} \) with respect to the true field in the \( L^2 \) norm. As in experiments true field is unknown, a criterion to choose the number of modes is given based on the error \( \delta_{kM} \) of the reconstruction with respect to the measured field and the ratio \( F \) between forward and backward derivatives of \( \delta_{kM} \).

Fig. 1. \( \delta_{kT}, \delta_{kM} \) (left axis) and \( F \) (right axis) versus the number of modes \( k \) used in the reconstruction.

A validation test based on synthetic experiment of the channel flow database at Reynolds number 4000 from John Hopkins Turbulence Database (Graham et al. 2013) is presented. In Fig. 1 the values of \( \delta_{kT} \) and \( \delta_{kM} \), are plotted; data are presented in non-dimensional form dividing by \( \delta_{kT} \), i.e. the error of the measured field with respect to the true one. A minimum is evident in \( \delta_{kT} \) with a reduction of 18% of the noise for the reconstruction with 1200 modes. This minimum is coincident with the transition of \( \delta_{kM} \) to a linear behavior of \( \delta_{kM} \) and to a value of \( F \approx 0.999 \).

The optimal number of modes found is used for a low order reconstruction of the flow field. In Fig. 2 the velocity spectrum of the field reconstructed is compared with the velocity spectra of the DNS field, of the measured field and of fields reconstructed with different number of POD modes. The reconstruction with 1200 modes closely follows the DNS spectrum for a wider portion of the wavelengths with respect to reconstructions with a larger number of modes than the measured spectrum and the spectra reconstructed with more (3000 modes) and less (300 modes) POD modes. The spectrum obtained using the optimal number of modes for the reconstruction follows with high fidelity the true one up to a wavelength of 70 pixels.

Fig. 2. Compensated transverse velocity spectra \( E_{\perp} \) in stream-wise direction versus wavelength \( \lambda \).

The proposed method is expected to contribute in enhancing the reliability of PIV as it allows for uncertainty reduction and robustness improvement. The spatial resolution might also indirectly benefit from it. The optimized low-order reconstruction allows for the use of advanced high-resolution interrogation algorithm since the random noise can be consistently reduced in post-processing.

References

