

An empirical method for efficient spectrum estimation from LDA data

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1. Introduction

Recovery of reliable spectral information from LDA data is fraught with difficulties that have been extensively considered in the past. In this paper, an empirical decomposition method is employed for removing noise from irregularly-sampled laser-Doppler anemometry (LDA) data that allows unbiased estimation of the underlying turbulence spectrum (power spectral density or PSD). Emphasis is placed on the high-frequency end of the spectrum which is strongly affected by two factors: a) instrument noise and b) filtering and step noise errors due to the resampling at equidistant time intervals required to compute spectra by conventional fast Fourier transforms. The denoising method (DN) employed here is based on the empirical mode decomposition (EMD) originally developed by Huang et al. (1999) for nonlinear and non-stationary time series analysis of regularly sampled data. It is intuitive, direct, a posteriori, and adaptive, with the basis of the decomposition being derived from the data. Because it uses no time scale it is well suited for processing LDA data which are irregular in time. In this work, the decomposition is applied on irregularly sampled LDA data in connection with the 'nearest-neighbor' (NN) interpolation (Broersen et al. 2000). The smallest time, or highest frequency, scales are treated as noise which is subtracted from the data. This operation is distinctly different from filtering in the frequency or time domain. The purpose of this paper is to demonstrate the implementation of the method in the context of LDA data analysis for efficient estimation of the power spectral density.

2. Results

Figure 1 shows a comparison of the spectra computed from hot-wire anemometry (HWA) and LDA data in the turbulent wake of a circular cylinder (data available at <http://www.nambis.de>). When the empirical mode decomposition is used to remove noise prior to the interpolation, the energy at the high-frequency end of the spectrum is overestimated due to the step noise introduced by the resampling process (Simon and Fitzpatrick 2004). Yet, the LDA spectrum (line 2) follows that from HWA (line 1) up to higher frequencies of about a quarter of the mean particle arrival rate than the uncorrected spectrum (line 3). If, however, noise removal is done after the interpolation, the HWA and LDA spectra agree remarkably well (cf. lines 1 and 4). An advantage of the new method is that the spectra computed do not exhibit variability at the high frequency end as opposed to other noise reduction methods (see, e.g., Simon and Fitzpatrick 2004). Since the method is purely

empirical, no presumptions about the spectral content of the flow are needed though an estimate of the noise variance can be useful. It might be argued that the removal of noise after resampling removes both the measurement and the resampling-induced noise and hence improves the spectral estimates. Another advantage of the proposed methodology is its robustness, i.e. it maintains the semi-definite property of the original data which is one of the shortcomings of the slot correlation method (line 5).

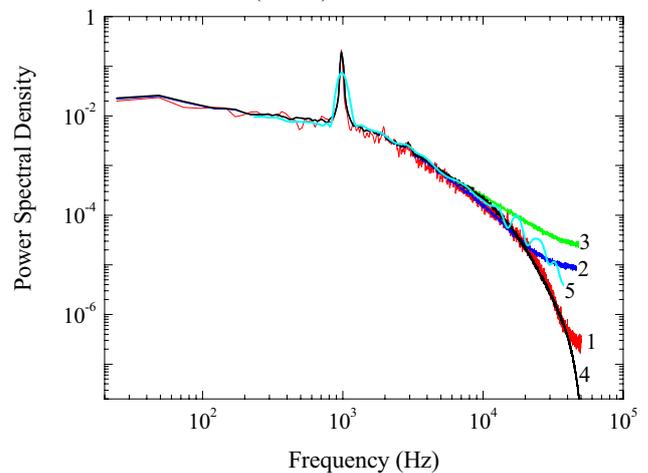


Fig. 1. Estimation of power spectral density in the wake of a circular cylinder. 1, HWA data; 2, LDA data with resampling at equidistant times (NN); 3, LDA data using DN and NN interpolation; 4, LDA using NN first, then DN; 5, Slot correlation method of Nobach (2002). All spectra were computed using the same FFT technique employing a Hanning window with 4096 points, 25% overlapping and no zero-padding. LDA data comprise approx. 10^6 samples at a mean particle arrival rate of 75 kHz.

3. References

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