Measurement of Velocity Field Spectra by Means of PIV

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Abstract

A Particle Image Velocimeter has been developed for the measurement of field velocity spectra. The velocity spectra are computed via the velocity auto-correlation function, obtained by correlating corresponding velocity fields at variable time delays. The PIV system features a single microcomputer that controls the dual camera (Kodak ES 1.0) arrangement, and is capable of acquiring up to 128 image pairs, per camera, at a maximum frame rate of 30 Hz. The system also synchronizes a pair of dual Nd-Yag lasers for the flow illumination. Using this system, field and point-wise spectra have been obtained and compare very well with those obtained by means of Hot Wire Anemometry. The special requirements in the PIV velocity measurement accuracy as well as the system's limitations due to quantization noise are discussed.

1. Introduction

PIV is a measuring technique capable of providing at different time instants the synoptic velocity field. However, the time resolution is limited to the framing rate of digital cameras used for the image recording, and is typically insufficient to record time sequences in rapidly evolving or turbulent flows. Therefore only time-averaged quantifies, such as the mean velocity and Reynolds stresses, can be obtained to characterize the flow unsteadiness. To obtain velocity spectra, PIV is usually supplemented with single point methods, such as Hot-Wire Anemometry or Laser-Doppler Velocimetry.

The objective of this study is to propose and develop a method that makes it possible to obtain field spectra with the PIV technique. The advantage of such an approach stems from the spatial nature of PIV technique. First, the technique provides a global view versus a local view of the distribution of time scales. Second, in addition to time correlation, time-space correlation and cross-spectra can be obtained, a daunting task if one is limited to the use of single point probes.

2. Principle

To achieve the aforementioned goal a Particle Image Velocimeter is implemented to measure the flow field spectra of the velocity and its derivatives, e.g., vorticity. The limitation imposed by the fixed and slow camera image acquisition rate was resolved by using two cameras to synchronously record the same flow region at variable separation times. The temporal auto-correlation function is obtained by measuring the velocity field at time τ and at t+τ, where τ can be varied to any delay amount. The correlation is function of the variable lag t and is obtained by the long time average of the repeated number of individual measurements, defined as:

$$R_X(x,y,\tau) = \frac{1}{N}\sum_{n=0}^{N-1} X_n(x,y,\tau)\cdot X_n(x,y,t+\tau) \quad (1)$$

In equation 1 X may represent any of one of the flow variables such as u and v (the velocity components), U (the velocity magnitude), or Ω (the vorticity), evaluated by means of PIV. The previous formulation indicates that the correlation function