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Wavelet analysis of unsteady flows: Application on the determination of the Strouhal number of the transient wake behind a single cylinder

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ABSTRACT

This paper presents experimental results of the accelerating and decelerating flow in the wake of a cylinder obtained by means of hot wire anemometry measurements in a wind tunnel with high blockage ratio. The analysis was done in Fourier and wavelet spaces. The Strouhal number for Reynolds numbers up to 3×10^4 was studied in a transient flow and compared with the results obtained from steady flows at several velocities uniformly distributed from Re = 1.7×10^3 to 3×10^4. Results show that the wavelet analysis is a valuable tool to deal with both transient and stationary random phenomena and that is able to capture the characteristics of the transient flow as well as the Fourier analysis can do with the steady state acquisitions.

1. Introduction

The flow on cylinders and the wake formed behind them is of great interest and object of many research studies. Single cylinders as well as cylinder arrangements simulate a wide range of practical situations, e.g. transmission lines, offshore structures and more complex arrangements, like tube banks of shell and tube heat exchangers.

Many articles found in the literature are concerned to equipment integrity, due to the close relationship between fluid flow around a solid surface or a structural element and the vibrations induced by the flow in the structure.

In general, fluid flow loads on a structure can be classified in static and dynamic loads. The former, due to the mean pressure variation of the flow along the structure, the latter, associated to pressure and velocity fluctuations due to vortex shedding and to the turbulence in the flow.

The first article relating frequency (of aeolian tones) and velocity of the flow over a bluff body was written by Čeněk (Vincenc) Strouhal in 1878 [1]. Since 1908, with the works performed by Bénard [2,3], studies of vortex shedding are found in the literature, with focus on the behavior of the wake of a single cylinder or two or more cylinders in steady state [4–9].

Unsteady flow results of flow visualization using Laser Induced Photochemical Anemometry are presented by Chu and Liao [10] for a Reynolds number range from 500 to 3000. Authors made also a comprehensive literature review.

Experimental results in turbulence are usually characterized by their mean values and through Fourier analysis, which provide information about the behavior of steady state phenomena in the frequency domain. This is not the case of field measurements, extreme situation of which would be the case of typhoon winds [11,12]. In transient flows, besides the variable mean values, additional phenomena may appear, as the flow velocity changes with time.

Steady state phenomena are a particular case of the transient general rule in nature. In engineering applications the steady state assumption is very useful and feasible in most situations. Nonetheless, in some situations a steady state approach may leave unnoticed some features of the phenomena.

Wavelets are valuable tools to analyze non-stationary time series and their possible singularities [13]. Wavelet transforms were used in applications such as presented in [14], to investigate the turbulence homogeneity at several scales, or to obtain power and cross spectrum, as in [15,16] or to detect coherent structures [17]. The orthonormal wavelet representation in experimental and numerical flow data sets was presented in [18]. Attention was given to single point measurements in steady state flow of a wake and a boundary layer to underline the capability of wavelets to demonstrate the intermittence in the smallest scales. For the interpretation of switching flows, wavelet analysis in addition to Fourier analysis was used [19,20]. Wavelet transforms were also used to study the vorticity structure in the far wake downstream of a cylinder [21,22], transient phenomena in tube banks [23] and the bistable flows in tube banks [24].

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