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SECTIONAL AERODYNAMIC FORCES AND THEIR LONGITUDINAL CORRELATION ON A VIBRATING 5:1 RECTANGULAR CYLINDER

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1 INTRODUCTION

The frequency and amplitude dependency of the aerodynamic action on oscillating elongated bodies has been widely investigated over the decades, both from the theoretical point of view and for practical applications. It is known that this dependency is the result of the existence of motion dependent forces, whose characteristics change as the vibration pattern changes. However, motion dependent forces are one component of the overall excitation, which is the combination of different mechanisms that in some cases simply superimpose, while in some others strongly interact with each other. Separation of the different components contributing to the overall aerodynamic force is of interest for a better understanding of the physics underlying the problem and for the purpose of modelling the aerodynamic action.

The relation of the aerodynamic forces to the torsional vibration of a 5:1 rectangular cylinder was investigated numerically in Ref. [1], through solution of the Navier-Stokes equations. The existence of a pronounced shedding-induced interaction for values of the reduced wind speed between 1 and 2 (based on the rectangle breadth) was recognised, together with a torsional flutter instability at a reduced wind speed of 6. The mechanisms of fluid-structure interaction were also investigated through the analysis of the work of the aerodynamic pressure distribution. On the other hand, the existence was pointed out in Ref. [2] of two types of vortex shedding flow instabilities on stationary rectangular cylinders, whose occurrence is related to the breadth-to-width ratio of the section. A comprehensive classification of possible aeroelastic instabilities of cylinders is given in Ref. [3]. The distribution of the unsteady pressures for different breadth-to-width ratios is also analysed by means of wind tunnel tests, together with its effect on flutter derivatives. The derivation of flutter derivatives from the unsteady pressure distributions allows an interpretation of the different flutter mechanisms and the fluid dynamics reason of their occurrence. In Ref. [4] the effects of turbulence on the mean and fluctuating pressure distributions on a 6.7:1 stationary rectangular cylinder is discussed, based on the results of wind tunnel measurements. Again based on numerical simulations, in Ref. [5] the aerodynamic characteristics of a variety of rectangular cylinders are investigated, with breadth-to-width ratios in the range of 0.6 to 8. In Ref. [6] the results of the application of Proper Orthogonal Decomposition (POD) to the pressure fluctuations measured in the wind tunnel on an oscillating bridge box section model are discussed. It was found that POD allows decoupling the force components associated with the different excitation mechanisms coexisting on the vibrating model. More generally Ref. [7] discusses the possibility of applying POD to pressure fluctuations, as a tool to investigate the mechanisms of wind loading of structures.

Besides the characteristics of sectional forces, in the analysis of the aeroelastic response of cylinders it is relevant how the aerodynamic action correlates spanwise. In Ref. [8] the results of wind tunnel tests on a section model of a fixed 5:1 rectangular cylinder are discussed. The model upper face was provided with 342 pressure taps, arranged in 18 arrays of 19. This allowed the analysis of the longitudinal coherence of pressure fluctuations at different locations on the lateral face of the rectangle. Finally, in Ref. [9] the results of similar measurements are shown for a vibrating cylinder, through the analysis of the spanwise correlation functions of the aerodynamic forces and of the stagnation and base pressures. It was pointed out that for increasing separation the correlation functions tend to a non-zero value for all vibrations regimes. This indicates the existence of a fully correlated portion of the aerodynamic force, which is observed to be in some cases as large as 89% of the total force.

In this paper the results of wind tunnel pressure measurements on a stationary and vibrating rectangular cylinder with a 5:1 cross section are presented. The investigation is aimed at characterising the sectional aerodynamic action at different vibration regimes, namely buffeting, vortex shedding lock-in and flutter, and its spanwise correlation.

Figure 1: Wind tunnel setup

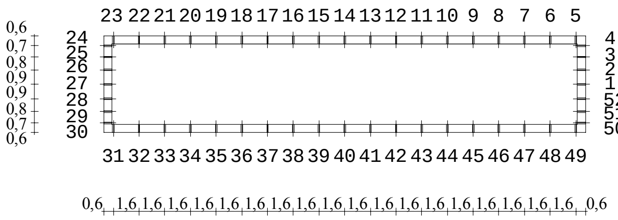

Figure 2: Instrumented cross section with 52 taps

2 WIND TUNNEL TESTS

Wind tunnel tests were carried in the CRIACIV boundary layer wind tunnel in Prato, Italy. The open circuit wind tunnel has a test section of 2.40 m x 1.65 m, with an upstream fetch of about 8 m. The 2.32 m long rectangular model, with a cross section of 30 cm x 6 cm was placed in the 2.40 cm wide test section, with the suspension system located outside the tunnel (Fig. 1). The model is made of carbon fibre composite to minimise the weight, and is provided with 342 pressure taps arranged in eight sectional arrays (seven of 30 and one of 52 pressure taps) and two longitudinal arrays of 40 taps, as shown in Fig. 2. The array of 52 taps was use for the characterisation of the sectional aerodynamic forces, the arrays of 30 taps were used to investigate the spanwise correlation of the forces, and the two longitudinal arrays were used to characterise the short distance spanwise correlation of pressure fluctuations. In addition to the pressure measurements, load cells were used to measure the total aerodynamic forces, and in the dynamic tests three laser displacement transducers were used to measure the model vibration. Measurements were taken in both smooth and turbulent flow at a Reynolds number of 63600, based on the model depth. First tests were carried out on the stationary model, and in a second stage the model was suspended in the vertical and torsional degrees of freedom, and measurements were taken at different reduced wind velocities.

3 ANALYSES AND PRELIMINARY RESULTS

For the particular breadth-to-width ratio of 5:1 considered, the three vibration regimes of buffeting, shedding induced vibration and flutter manifest themselves, depending on the reduced wind speed. In smooth flow a dominant shedding induced heaving vibration was found for values of the reduced wind speed lower then 3 (based on the heaving frequency), and a torsional flutter with a onset reduced speed in the range of 4 to 4.5. At other values of the wind speed the model vibration is associated with the effects of signature turbulence. The aeroelastic behaviour experienced by the model allowed not only comparison of the results obtained in the dynamic tests with those obtained in the static tests, but it allowed also comparison of the results obtained with the same vibration amplitude in the different vibration regimes. As an example of the results obtained, Fig. 3 shows the mean and fluctuating pressure distribution on the fixed model, together with the distribution of the skewness and kurtosis coefficients. These pressure distributions are heavily modified by the presence of turbulence, not only through the increase of the pressure fluctuations on the windward face, but also through the change of the mean and fluctuating pressure distributions on the upper face. This change reflects an change in the aerodynamics, which is better analysed through the spectra of the pressure fluctuations. In Fig. 4 the spectra of the pressure fluctuations at pressure tap are shown, as measured in smooth and turbulent flow, which confirm the different nature of the pressure fluctuations in the two flow regimes. Finally, in Fig. 5 the longitudinal cross correlation of fluctuating pressures at points located on the upper face of the model, 0.18 the model breadth from the trailing edge. The figure shows that the addition of turbulence does not affect the correlation at small separations, but it does for separations larger than 8 times the model depth.

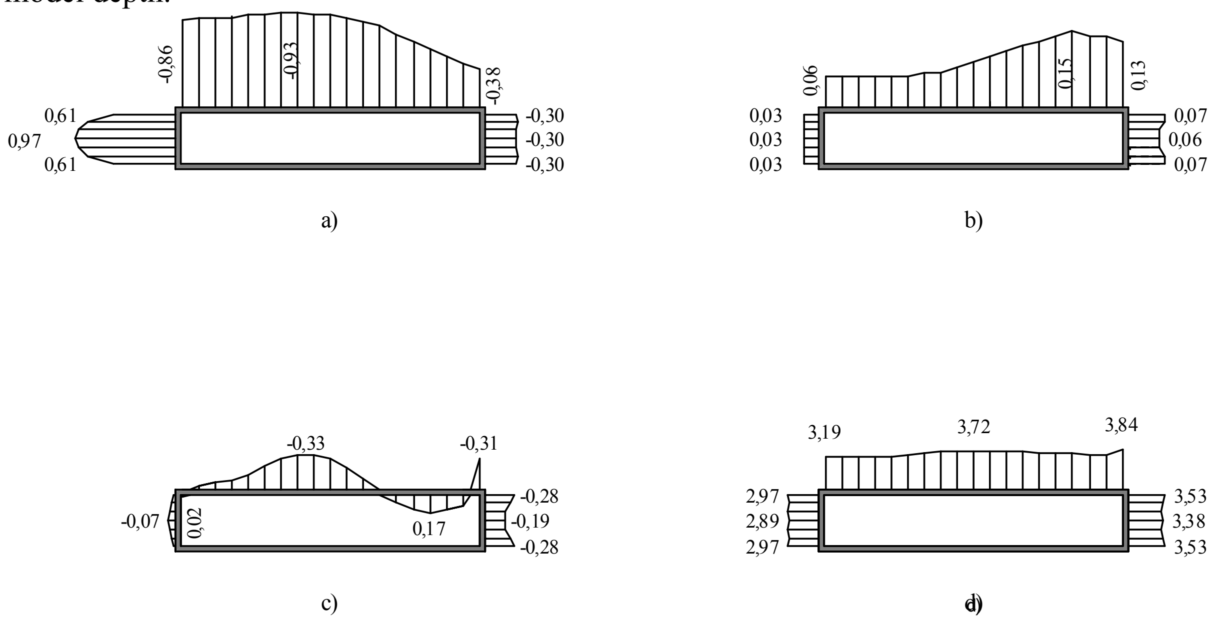

Figure 3: Pressure distribution in smooth flow: (a) mean, (b) RMS, (c) skewness, (d) kurtosis

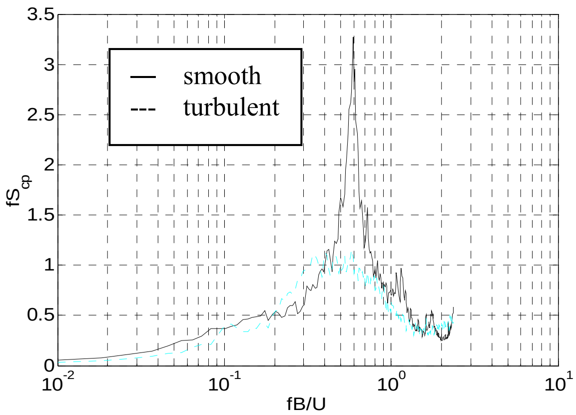

Figure 4: Spectra of the pressure fluctuations at pressure tap 5

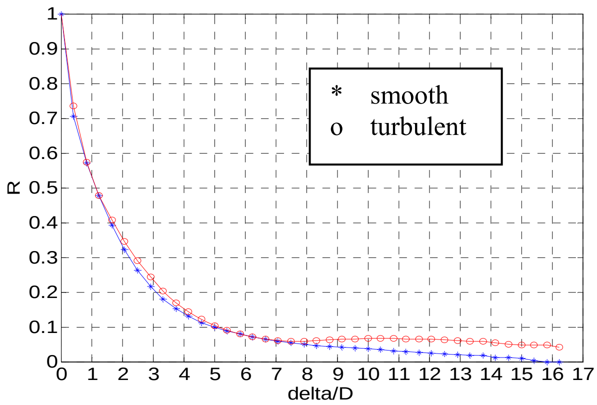

Figure 5: Longitudinal cross correlation of the pressure fluctuations

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