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Brief Communication

Aerodynamic external pressure loads on a semi-circular bluff body under wind gusts

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ABSTRACT

This brief communication concerns the unsteady aerodynamic external pressure loads acting on a semi-circular bluff body lying on a floor under wind gusts and describes the theoretical model, experimental setup, and experimental results obtained. The experimental setup is based on an open circuit, closed test section, low speed wind tunnel, which includes a sinusoidal gust generating mechanism, designed and built at the Instituto de Microgravedad "Ignacio Da Riva" of the Universidad Politécnica de Madrid (IDR/UPM). Based on the potential flow theory, a theoretical model has been proposed to analyse the problem, and experimental tests have been performed to study the unsteady aerodynamic loads on a semi-circular bluff body. By fitting the theoretical model predictions with the experimental results, influencing parameters of the unsteady aerodynamic loads are ascertained. The values of these parameters can help in clarifying the phenomenon of the external pressure loads on semi-circular bluff body under various gust frequencies. The theoretical model proposed allows the pressure variation to be split into two contributions, a quasi-steady term and an unsteady term with a simple physical meaning.

1. Introduction

In the paper of Navarro-Medina et al. (2012), results have been obtained concerning the dynamics of a body lying on a floor, attached to a hinge, and exposed to an unsteady flow featuring high intensity gusts, which is a model of the initiation of rotational motion of ballast stones due to the wind generated by the passing of a high-speed train. This paper includes the description of the gust wind tunnel, designed and built at the Instituto de Microgravedad "Ignacio Da Riva" of the Universidad Politécnica de Madrid (IDR/UPM) and the experimental results that have been obtained by using this gust wind tunnel. The theoretical model and research that justifies the development of this gust wind tunnel can be found in Sanz-Andres and Navarro-Medina (2010). In the present work, the aerodynamic external pressure loads acting on a semi-circular cylinder under various gust frequencies have been investigated by using the same gust wind tunnel. The performance of this tunnel has been improved by installing an automatic speed control system for the gust generation motor, and a gust frequency measuring system. The new gust frequency control greatly facilitates the experimental investigation of the gust wind loads on bluff bodies. The work presented here is a continuation of this research line.

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Concerning the study of external pressure on bluff bodies under wind gusts, some interesting works related to unsteady aerodynamic loads can be found. For example, Leweke et al. (2008) have investigated, both computationally and experimentally, the resulting viscous fluid flow due to collisions without rebound of generic bluff bodies with a wall. Their work is focuses on the complex energy exchanges between the bluff bodies due to the collisions with a solid surface. But the unsteady fluid loads acting on the surface of the cylinder are not presented, which are needed in our case to estimate the distributed loads acting on the bluff body.

The onset of asymmetry in the near wake of a circular cylinder and elliptic cylinders of various thicknesses to chord ratios has been investigated by Nair and Sengupta (1996). As an extension to this work, the flow past an elliptic cylinder, under different Reynolds numbers and angles of attack has been investigated by Nair and Sengupta (1997), they employed numerically solving the two-dimensional, unsteady, incompressible Navier–Stokes equations and compared the theoretical results obtained with the results of Ohmi et al. (1990). Their work focuses primarily on pressure fields acting on an elliptic cylinder under Reynolds number ranges from 3000 to 10 000, angle of attack of the fluid flow $\alpha=10^{\circ}$, 12° and 30° and cylinder thickness to chord ratios $t/c=0.1$ and 0.25. Their work is devoted to the characterization of unsteady incompressible two-dimensional flows around an elliptical cylinder under various angles of attacks by solving the unsteady Navier–Stokes equations.

The streamwise vibrations of a body have been investigated by Naudascher and Rockwell (1994). This study can somehow be adapted to the streamwise oscillations of the flow superposed to a mean value. According to them, in an unsteady flow condition, the symmetry of the shear layers detached from both sides of the cylindrical body is similar to the case of an isolated vibrating cylinder. Their book includes the studies of the instability induced excitation raised from the development of flow instabilities and also includes such phenomena as vortex shedding from bluff bodies. From the inspiration obtained by the experimental setups and the conclusions in this book, in the present paper a semi-circular cylinder bluff body has been selected as a testing model for the experiments. A numerical and experimental investigation into the unsteady incompressible laminar wake behind a circular cylinder has been conducted by Braza et al. (1986). Their study deals with the dynamic characteristics of the pressure and velocity fields of the wake and presents the initiation mechanism for vortex shedding and the evaluation of the unsteady forces acting on a body at Reynolds numbers 100, 200 and 1000. However, this work does not consider the Reynolds numbers above this range. In their work the governing equations are also derived from the Navier–Stokes equations. In all the above works the authors did not comment on the distribution of the unsteady flow loads on the cylindrical bluff body under unsteady flow conditions. Roshko (1954) has conducted a number of experiments on bluff bodies under steady flow and evaluated the influencing parameters of the aerodynamics forces acting on those bodies. In the present paper, the results obtained have been compared with the results of Roshko (1954). Most of the published works concerning the aerodynamics loads on bluff bodies are based on steady flow conditions and very few works are available concerning unsteady flows (see above mentioned papers), which is the case considered here.

As a representative example of a bluff body (that can also be treated analytically) a semi-circular cylindrical body immersed in an unsteady flow has been considered, and an analysis of the aerodynamic forces acting on this bluff body is made. This analysis has been approached in two ways. On the one hand, a semi-empirical mathematical model of the pressure distribution over a circular cylinder subjected to an unsteady flow, based on the two-dimensional potential flow theory, has been developed. On the other hand, an experimental test campaign has been performed on a model of a semi-circular cylinder, using the gust wind tunnel, designed and built at IDR/UPM.

This paper is organized into the following sections: the main results of the flow characterization in the test section and the experimental setup for measuring the pressure acting on the test body are presented in Section 2; the theoretical model considered for the flow around the bluff body is presented in Section 3; results from the experiments and from the model are compared in Section 4; finally, in Section 5 conclusions are drawn.

2. Experimental setup

In this section, the characteristics of the flow (measured in the test section by a hot-wire anemometer (Dantec Dynamics, version 4.10, with 1D probe)), the experimental setup, and the test procedure used to measure the pressure variation acting on the semi-circular cylinder (see Fig. 2(a) and (c)) are presented. Concerning the flow characterization in the wind tunnel empty test section, the flow measurements are performed under nominal gust frequencies $f_g^N=2, 4, 6, 8$ Hz; mean speed of gusty winds $U_{mv}=2.5$–5.5 m/s; wind tunnel rotating gates blockage area $L_{gc}=380$ mm, and flow in the test section is the turbulence intensity of the inlet flow in the test section is reduced by using a honeycomb plus a foam block (see Navarro-Medina et al. (2012) for more information about these parameters). From the experimental data, it has been noted that the measured flow velocity follows a sinusoidal shape with some small drifts. Therefore, by using a Matlab programme this data had been fitted to the sinusoidal function, U^F, given by

$$U^F = U^E_{mv} + U^E_a \sin(\omega t + \varphi), \tag{1}$$

where U^E_a is the amplitude of the signal, U^E_{mv} is the mean value of measured flow, ω is the angular frequency, and φ is the phase referring to the pass of the rotating gate by the closing position. These values are presented in Table 1.

In Fig. 1 the variation of the measured flow in the test section, U^E, and the sinusoidal curve fitted data, U^F, are presented for $f_g^N=2$ and 8 Hz.