VIV response of a suspended sphere nearby the critical Reynolds number

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Abstract

The Vortex-Induced Vibration of a sphere connected to a flexible beam is investigated in air for Reynolds numbers including the critical value. For this value (Re_C=3 10^5), wake disorganization is expected in a static configuration. This fundamental fluid-structure interaction characterised by an axisymmetric configuration leads to vibrations in the lateral and longitudinal directions. Similarly to the well-known circular cylinder, a lock-in phenomenon will take place due to the effect of the motion of the body on the shedding process. An experimental aeroelastic model is designed, instrumented and tested in the wind tunnel of University of Liège. The objective is twofold: (i) solve a practical wind-engineering problem (a spherical suspended streetlight) and (ii) propose a fundamental investigation of the VIV of a smooth sphere for sub-critical and critical Reynolds numbers.

1 Introduction

The configuration of a rigid sphere supported in a fluid by a flexible beam can be encountered in many hydrodynamic applications, where tethered bodies are concerned: marine buoys, balloons, objects behind ships, underwater mines, etc.. Williamson, Govardgan and Jauvtis [1-3] carried out important experimental works on this topic, shedding light on the occurrence of three regimes of vibration. Behara and co-workers recently published numerical investigations of the same systems [4,5]. All these works concern the behaviour of a sphere, suspended or tethered at low Reynolds numbers ($300 \leq Re \leq 1200$). These experimental/numerical simulations are performed in water and characterised by low mass ratio (m*=mass of the sphere / mass of the fluid <1).

In the scope of this work, the Reynolds number ranges between 4 10^4 and 6 10^5, enclosing the critical regime of a smooth sphere [6]. The application motivating this study concerns a spherical luminaire (diameter 60cm) suspended to a cylindrical tube (diameter 4cm, length 370cm) and the above-mentioned Reynolds range corresponds to the wind speed range of 0.25m/s up to 15m/s of urban environment. The mass ratio (m*~50) is much higher than the values found in the literature. The purpose of this work is to analyse the Vortex-induced Vibration (VIV) response of this sphere in order to quantify the peak responses and the extent of the lock-in range of the phenomenon throughout the critical Reynolds range.

2 Methodology

The analysis is based on wind tunnel tests of an aeroelastic model representative of the full-scale prototype. For that purpose, a reduced scale model is designed and built. Figure 1 shows a sketch of the model and its instrumentation. It consists in a wireless 3 components accelerometer located inside the sphere, a force balance connected to the supporting beam and a cobra probe in the wake of the sphere.

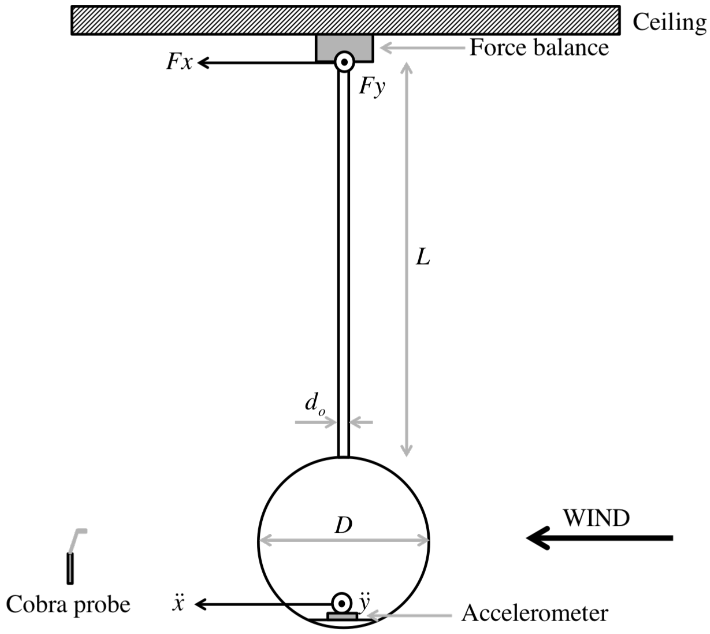

Figure 1. Sketch of the model and instrumentation.

The Reynolds and Scruton similarity laws are enforced in order to transpose directly the measured VIV responses into useful results for the design of the prototype. In addition the Strouhal relation must be conserved because of the unsteadiness features of the flow and the resulting vibrations of the structure.

The left part of table 1 shows the ratios of length, velocity, frequency and mass. The right part of the table presents the characteristics of the prototype and the model. These quantities will be verified on the experimental model through a modal analysis at wind-off conditions.

λ_L	1/4
λ_U	4
λ_f	16
λ_M	1/64

	D	d_o	d_i	L	M	f
Prototype	600mm	40mm	32mm	3700mm	8kg	1.46Hz
Model	150mm	10mm	8mm	375mm	145g	21.0Hz
Error	-	-	-	-	+15.7%	-0.95%

Table 1.Scaling factors and characteristics of the prototype/model

3 Challenges of the study

Figure 2 depicts the flow characteristics of a static smooth sphere as a function of the Reynolds number. It is observed that the Reynolds number corresponding to the frequency matching and apparition of VIV (denoted $Re_{VIV} = 2\ 10^5$, in red in figure 2) is close to the critical Reynolds number ($Re_C \sim 3\ 10^5$). Hence the flow regime will change during the VIV lock-in and influence the VIV response of the sphere. The opposite situation is also true: VIV vibrations will affect the shedding process, as it is well-known for circular cylinders.

The perfect matching of the Reynolds similarity law is enforced by a velocity ratio of $\lambda_U=4$, balancing the geometric scaling ($\lambda_L=1/4$). The surface roughness of the model (measured to $k/d=5x10^{-5}$) corresponds to a smooth surface, in comparison with the works of Achenbach [6]. The dynamic part of the scaling is reached by adapting the length L of the supporting tube. Consequently the aerodynamics is adequately scaled and the effect of the disorganisation of the flow will be captured during the wind tunnel test campaign.

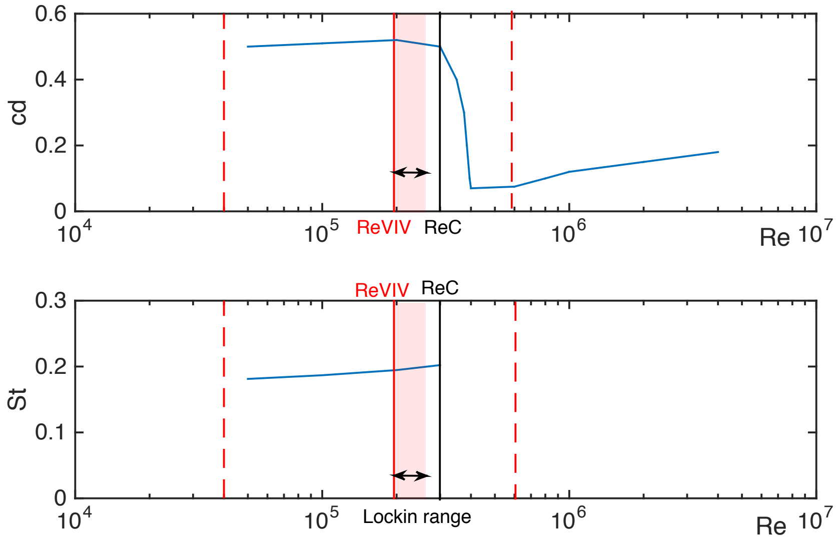

Figure 2. Cd and St for a static smooth sphere vs Reynolds number (reproduced from [6])

4 Outputs of the study

Two types of answers will be given at the end of this work:

Practical application of the streetlight:

- What are the peak displacements along *x* and *y* when the sphere undergoes VIV?
- What is the extent of the lock-in range for this specific configuration?
- What is the effect of VIV on the fatigue life of the structure?

Fundamental study of the VIV of a smooth sphere for sub-critical and critical Reynolds numbers:

- What is the effect of the flow disorganisation on the VIV response (extent of the lock-in range and amplitude of vibration)?
- What is the effect of the mass ratio?
- What is the effect of the flow regime on the VIV response? The scaling of the aeroelastic system can be changed by reducing the velocity ratio (λ_U taking values of 3, 2 and 1) and adapting the length of the supporting tube.

References

[1] C.H.K. Williamson, R. Govarghan, Dynamics and forcing of a tethered sphere in a fluid flow, Journal of Fluids and Structures (1997) vol. 11, pp. 293-305

[2] N. Jauvtis, R. Govarghan, C.H.K. Williamson, Multiple modes of Vortex-induced vibrations of a sphere, Journal of Fluid Mechanics (2001) vol .15, pp. 555-563

[3] R. Govarghan, C.H.K. Williamson, Vortex-induced vibrations of a sphere, Journal of Fluid Mechanics (2005) vol. 531, pp. 11-47

[4] S. Behara, I. Borazjani, F. Sotiropoulos, Vortex-induced vibrations of an elastically mounted sphere with three degrees of freedom at Re = 300: hysteresis and vortex shedding modes, Journal of Fluid Mechanics (2011), vol. 686, pp. 426-450

[5] S. Behara, F. Sotiropoulos, Vortex-induced vibrations of an elastically mounted sphere: The effects of Reynolds number and reduced velocity, Journal of Fluids and Structures Mechanics (2016), vol. 66, pp. 54-68

[6] E. Achenbach, The effects of surface roughness and tunnel blockage on the flow past spheres, Journal of Fluid Mechanics (1974), vol. 65, part 1, pp. 113-125