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Fluid-structure interactions on a 3D bluff body pendulum at high Reynolds number

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1 Introduction

Fluid-structure interactions (FSI) occurring on a bluff body is a wide subject raising issues ranging from structural safety in wind or water engineering to energy harvesting from flows. FSI on 2D cylindrical bodies have multiple practical applications in civil engineering and have been extensively studied [1]. Less investigated, the interaction between a 3D tethered bluff body and the surrounding wind has an importance in many cases, such as safety issues concerning the loads lifted by a tower crane or in cable car engineering.

The type of FSI that may occur is related to the reduced velocity U^* which characterizes the ratio between fluid and solid frequencies [2]. It is defined as the ratio between the advective frequency of the flow U_0/D - based on the free stream velocity U_0 and the side length D of the solid - and the natural frequency f_0 of the solid.

This work tackles the different type of FSI that may occur on a 3D bluff body pendulum in a non-turbulent flow at high Reynolds numbers (10^5). The study comprises the experimental study of different blunt bodies, and the numerical investigation of simplified configuration to elicit the key physical mechanisms.

On the experimental side, complementary setups at different scales are used in three closed loop wind tunnels to explore a wide range of reduced velocities. Local pressure measurements are used to compute aerodynamic loads and the pendulum dynamics is measured using a motion tracking by cameras.

A crossflow swinging motion of the cube pendulum produced by galloping is observed when the front face of the cube is normal to the free stream and results in the exponential growth of the swinging motion. The flow mechanisms responsible for the onset of this instability are investigated and the validity of the quasi-steady theory is assessed.

Another type of instability fully driven by unsteady mechanisms is currently studied.

The numerical investigation consists on the DNS simulations of the flow around blunt body under a prescribed harmonic motion. Different amplitudes and reduced frequencies are investigated, and the resulting lateral forces are computed. Harmonic balance analysis will be used to investigate oscillations onset and saturation.

2 Results

The galloping instability on the cube pendulum occurs when the cube makes a static yaw angle $\beta \in [-9^\circ, 9^\circ]$ with the mean flow. The quasi-steady linear model based on the linearized momentum equations leads to the same Den Hartog criterion [3] as for galloping 2D cylinders and proves to be a relevant tool to predict the stability of the cube pendulum. Despite the 3D shape of the cube, the observed galloping instability seems to be driven by the same physical mechanisms as the galloping instability observed on bidimensional square cylinders [1, 4].

The swinging motion induced by galloping saturates and unsteady mechanisms arise during the saturation process for the lowest reduced velocity investigated ($U^*=18.5$). A phase delay between the wake and the pendulum dynamics produces an aerodynamic braking force when the cube pendulum goes downward, responsible for a premature saturation of the pendulum oscillation. The aerodynamic time delay has been characterized and is found to scale with the flow advective time and to produce unsteady effect only when it is of the order of magnitude of the maximum time-variation rate of the yaw angle β . Consistently, the cube pendulum follows a more quasi-steady behaviour for higher reduced velocities as the aerodynamic response delay is shorter.

An experimental campaign has been dedicated to the other type of instability observed, with pressure measurements and visualization by wool threads. This instability exhibits large elliptical oscillations, unlike

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galloping, and can appear only after a specific burst and/or under specific conditions of the upstream flow. It has been observed on all the bluff bodies investigated and with several types of front edges (sharp or rounded). We are still working on the type of FSI corresponding to this instability and its mechanisms. Several observations have been made so far indicating that flow reattachment dynamics might be at stake. An unsteady delay between the pendulum and the side wakes dynamics, observable through the fluctuation of the reattachment point, has been identified. Finally, in some configurations, side vortices might play a role in the onset of this instability.

Preliminary numerical simulations were obtained for a 2D configuration, Reynolds number of 1000, a reduced frequency of 18, and the amplitude was chosen as to induce a maximum angle of attack of 12° . The resulting flow field and lateral forces are shown in Figure 2 and Figure 3. Boundary layer detachment/reattachment and vortex shedding were observed. The lateral loads exhibit a dominant signal corresponding to the period of oscillation, which is disturbed by, we assume, the natural vortex shedding dynamics.

By the time of the presentation, the numerical database will be expanded to encompass different amplitudes and frequencies of oscillations, and the resulting lateral loads will be investigated in the frequency domain and using harmonic balance methods.

3 Conclusion

This study shows that several type of FSI can occur on a bluff-body pendulum. The quasi-steady theory proves to be an efficient tool to predict the galloping instability on a cube pendulum as far as no unsteady phenomena occur. The study of the other instability fully driven by unsteady mechanisms is ongoing. The investigation of low reduced velocities also turns out to be critical in future works about FSI on a bluff body pendulum. Indeed, for real-world applications concerning cable cars for instance, the range of reduced velocities is low and unsteady effects are expected to be dominant.

Numerical simulations are a valuable tool to study the physics of the dynamics, allowing to investigate simplified configurations, such as prescribed movements, which are not trivial to be obtained experimentally.

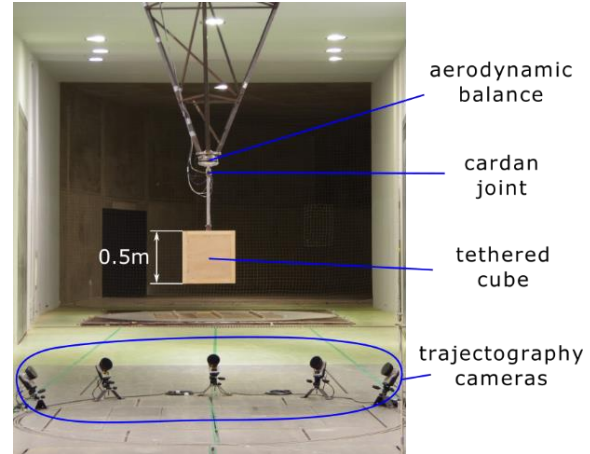


Figure 1 : Setup of the cube pendulum in the Jules Verne wind tunnel in CSTB, Nantes

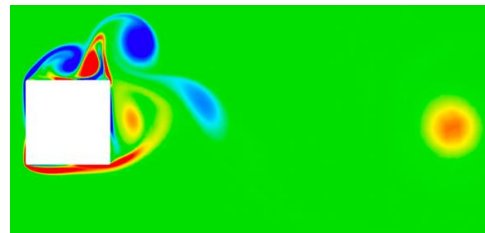


Figure 2 : Snapshot of the vorticity field for the flow around the oscillating body during a downward movement.

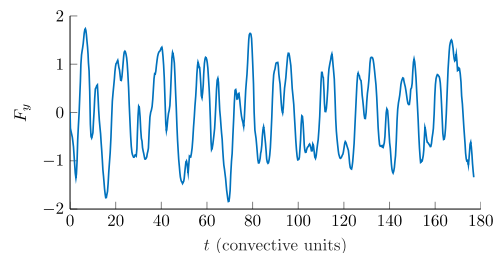


Figure 3 : Fluid lateral forces on the oscillating body.

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