Bistability of a pendulum in a wind channel

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Résumé

Simple systems tend to prove themselves much more complex that they seem to be, in particular when they are coupled to turbulence. A clear example of this is the pendulum. Well-understood since the 17th century, yet once coupled with another pendulum or a flow, its behavior can change from the classic harmonic oscillation towards more chaotic responses. A previous thorough study of such a coupling is presented in Reference [1]. The experimental setup, which we have in common, is a simple disk pendulum placed in a wind tunnel. By measuring the equilibrium angle of this pendulum, we can trace back the force balance and get a hang of the angular dependency of the aerodynamical drag coefficient Cd and lift coefficient Cl. When the pendulum consists of a disk facing the flow, a striking phenomenon occurs: two stable positions coexist over a range of flow velocity. This bistable regime is determined by the aerodynamic coefficients. By increasing or decreasing the velocity step by step, we have an overview of the equilibrium landscape. The bistable zone is hysteretic, due to the asymmetry of the associated potential wells, established by the balance between gravity and aerodynamical forces (drag and lift). Interestingly, ambient turbulence and the pendulum own dynamics can trigger transitions between the two stable branches. Our study reports on the investigation of such transitions. They happen in both "laminar" (turbulence rate 0.2%) and low turbulent (turbulence rate 2%) environments. By increasing the turbulence rate up to 20%, the bistable region (hence the transitions) reduces as far as to disappear, thus suggesting that the ambient turbulence level may have a significant influence on the aerodynamical properties of the disk, independently of the Reynolds number, simply based on mean flow velocity and disk diameter.

The turbulence level has also a great impact on the statistics of the transitions. An automated experiment to study the transitions over long time scale has enabled us to get statistically well-resolved escape-time distributions as well as an overview on the waiting time dynamics. Considering the variations of the angular position of the pendulum to be a direct visualization of the fluctuations of the aerodynamical (lift and drag) coefficients, the influence of the ambient turbulence is especially visible on the statistics of strong deviations from the time-averaged equilibrium position. Counterintuitively, we observe that these extreme events are of great amplitude in laminar flow, while there almost disappear at moderate turbulence level. It might be the expression of a competition between vortex shedding and turbulence in dictating the dynamics of the pendulum.

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