Phenomenological model for torsional galloping of an elastic flat plate due to hydrodynamic loads

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Abstract: This study investigates the torsional galloping phenomenon, an instability type flow-induced oscillation, in an elastic structure due to hydrodynamic loads into the water current. The structure applied here is a rectangular flat plate with an elastic axis in its mid-chord length. The elasticity is provided by torsion spring. The flat plate has only one degree of freedom which is rotation in pure yaw about its axis. It is observed that as the current speed is higher than a critical velocity, the flat plate becomes unstable. The instability leads to torsional galloping occurrence, as a result of which the flat plate begins to yaw about the elastic axis. By testing two different chord lengths each with several torsion spring rates, the flat plate behavior is investigated and three different responses are recognized. Then, a phenomenological model is developed with the original kernel in the form of the van der Pol-Duffing equation. The model explains these three responses observed experimentally.

Key words: torsional galloping, flow-induced oscillation, phenomenological model, van der Pol-Duffing equation

Introduction

Flow-induced oscillations are results of the interaction between fluid flow and elastic structures. They are usually tried to be suppressed, because of their destructive effects on structures. Nevertheless, if they are exploited, they have a great potential to be applied in energy extraction. Its feasibility has been proved through several scaled models and prototypes [1,2]. Therefore, to have an analytical approach to deal with flow-induced oscillation might be of interest, for both suppression and exploiting.

Flow-induced oscillations are classified in two categories; resonance type and instability type as shown in Fig.1 [3]. In the resonance type, the flow-induced forces and moments do not depend on the structural motion. In other words, the elastic structure begins to oscillate if the frequency of the oscillatory forces corresponds to its natural frequency. The oscillatory force can be induced either by the oscillating incoming flow, which leads to buffeting, or by the vortex shedding, which causes vortex-induced vibration (VIV). On the other hand, in the instability type, the forces vary with time as a result of the motion of the structure, and increase the oscillation amplitude. The instability is called as flutter when the resulting oscillation is in two or more coupled degrees of freedom, and as galloping when the oscillation has only one degree of freedom with relatively high amplitude, whether translational or torsional.

![Flowchart for flow-induced oscillation](image)

There are different ways to model flow-induced oscillations. In flow-induced oscillations of resonance type, since the driving force or moment comes from the oscillatory stream, its structure is nearly sinusoidal [3]. Therefore, the harmonic modeling is very much adequate. On the other hand, in flow-induced oscilla-