INSTABILITY OF FLOW OVER A SIMPLY SUPPORTED PLATE

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Keywords: Flutter, simply supported plate, cantilever plate, modal analysis

Abstract

The stability of cantilever plate in axial flow is of great importance in engineering. Many methods for this theoretical model have been applied. The first study was given by Kornecki [1] with Theodorsen's thin airfoil theory and Kutta condition. Huang [2] carried out a time-domain study using the same combination of potential flow with the viscous effects embedded in the Kutta condition. Watanabe [3] adopted the Navier-Stokes equation, and also gave a collection of the comparison between various experiments and theories on the flutter of a cantilever plate. His summary showed that the theoretical results by various methods were consistent, but typical measured flutter speed was about twice as much as the theoretical predictions.

This paper aims to investigate the effect of the boundary condition at the leading edge of a flexible plate on the flutter occurrence. We extend our numerical method originally written for a cantilever plate to simulate the flutter of a simply supported plate, and conduct the modal analysis for the new configuration. In our model, a rectangular flexible plate is immersed in the axial flow of a wind tunnel. The leading edge of the plate is simply supported, while the trailing edge is free. The plate vibration is governed by the linearized Euler-Bernoulli equation. The aerodynamic loading is calculated by an accurate pseudo-spectral method. The plate upward displacement η and the fluid loading Δp on the plate are expanded in terms of the in-vacuo modes of a simply supported beam. With the standard Galerkin procedure, a system of linear equations for mode coefficients is established. The control parameters of the coefficient matrix are normalized angular frequency of the vibration ω and normalized mean-flow speed U. Eigen frequency and critical flutter speed are found when the system of linear equations has non-trivial solutions.

An example for the eigen solution is given in Figure 1. In this example, the mass ratio m_p is set to be 1.46, and the damping ratio of the system δ_d is set as zero. The left sub-figure in Figure 1 shows 22 instantaneous vibration positions (thin lines). The solid and dashed thicker lines represent the real and imaginary parts of the eigen solution $\eta(x)$, respectively. The significant modes are limited to the first and second. The right sub-figure in Figure 1 shows the complex fluid loading on the plate. The rate of energy transfer from the flow to the beam is investigated in the modal analysis. It is found that the flutter is caused by the coupling between the first and second in-vacuo modes, the latter being the dominant source of instability with energy transfer from the flow to the vibration of the first in-vacuo mode.

The dimensional critical flutter speed and flutter frequency are compared between the simply supported and the cantilever plate for $m_p \in [1, 4], \delta_d = 0$, as shown in Figure 2. In this range of mass ratio, there are little in-vacuo modes above

the modal index of 2, and the configuration of the coupled mode is similar to Figure 1(a). The solid line in Figure 2 is the ratio of dimensional critical flutter speed for simply supported and cantilever, and the dashed line is the ratio of dimensional angular frequency. The result illustrates that the two configurations have similar flutter speeds, while the vibration frequency for simply supported is lower than that for the cantilever. This suggests that the boundary condition at the leading edge is not the main factor for the flutter instability and the dominant parameter controlling the flutter instability is the bending stiffness of the plate.

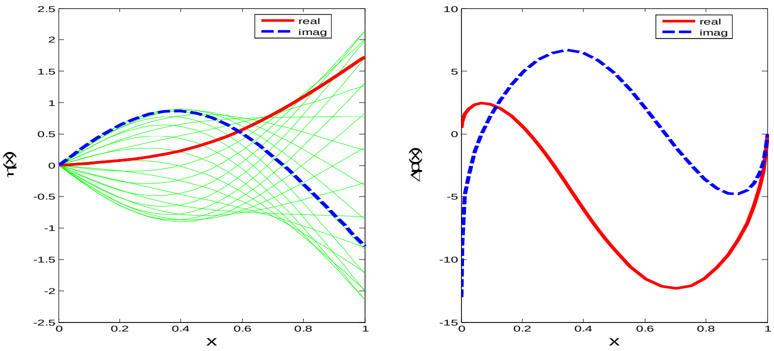

Figure 1: Details of the coupled flutter mode for simply supported

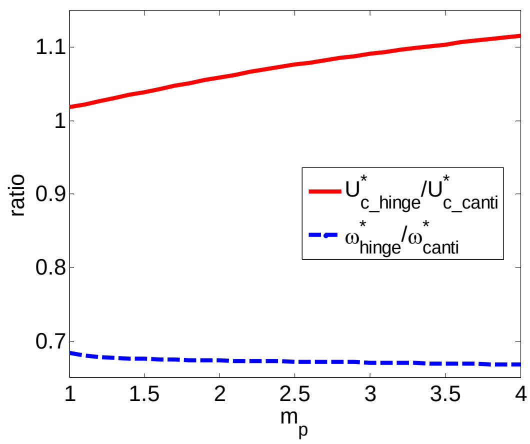

Figure 2: Comparison of the critical flutter speed and the flutter frequency between the simply supported and cantilever configurations.

References

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