THE EFFECT OF LOCALISED STIFFENING ON THE STABILITY OF A FLEXIBLE PANEL IN UNIFORM FLOW

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1. Introduction

This paper considers the classical aero/hydro-elastic system comprising a flexible panel exposed to a one-sided incompressible uniform flow; linear studies include [1-5]. The system is representative of the high Reynolds number situations found in many engineering applications that range from the hydrodynamic loading of panels making up the hull of a ship through to the axial wind loading of glass panels of curtain walls that have become a feature of contemporary high-rise buildings for both aesthetic and thermal-control reasons. In such applications, the concern is that at some critical speed the panel loses stability, usually through divergence that can lead to a buckled nonlinearly saturated state, e.g. [6,7], or a highly destructive flutter instability at higher flow speeds.

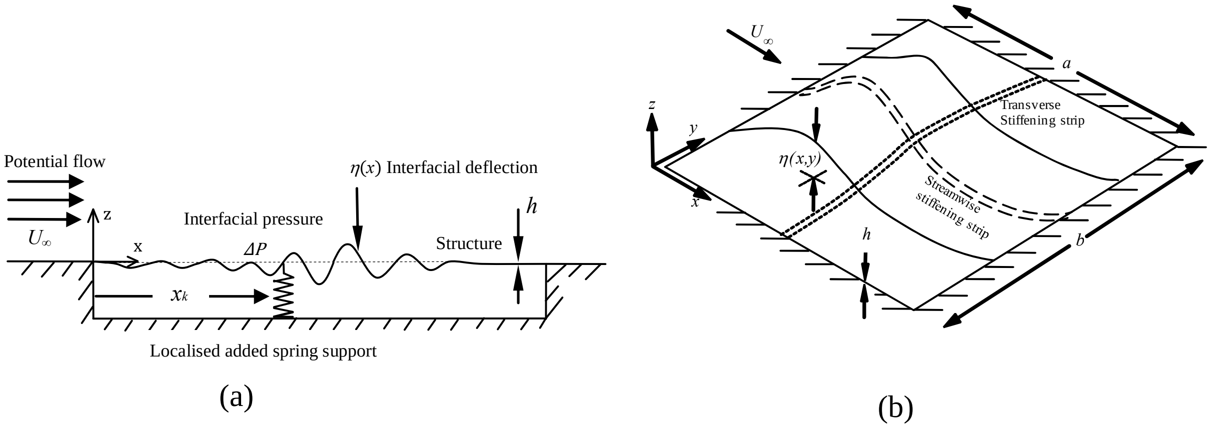


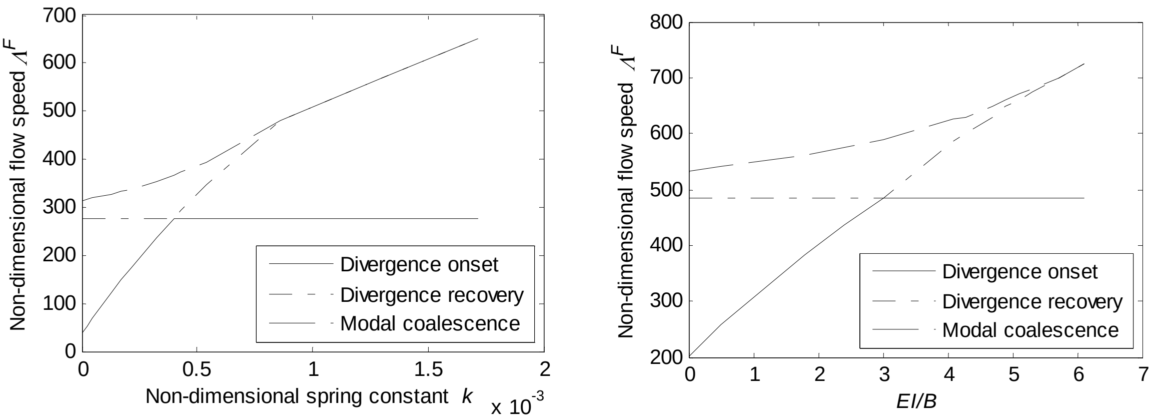
Figure 1: Schematics of the (a) two-dimensional (side view), (b) three-dimensional (isometric view) problems studied wherein a uniform flow interacts with a flexible panel that has localised stiffening; in (a) a spring support is added while in (b) a stiffening strip, that may be in either the transverse or streamwise direction, is bonded to the underside of the panel.

Strategies to postpone critical flow speeds to values beyond the speed for which a panel is designed are usually based upon material selection or uniform thickening of the panel that results in increased cost and dead weight. By contrast, the goal of the present paper is to control instability through the judicious use of highly localised structural inhomogeneity (stiffening) based upon a full understanding of instability modes. Our previous work [8,9], has demonstrated the utility of this stabilisation strategy for the two-dimensional system of Fig. 1a. A preliminary exploration of the effect of a transverse stiffening strip on the equivalent full three-dimensional system of Fig. 2b was presented in [11]. In this paper we extend the hybrid of theoretical and computational methods of [10] to conduct an eigen-analysis of the three-dimensional system when a streamwise stiffening strip is incorporated. Our immediate goal is to determine the effectiveness of this type of additional structural component on stability relative to transverse stiffening. The broader goal is to optimise the use of multiple stiffeners to postpone instability of the panel for a given material (weight) cost of added structural material.

2. Overview of Methods

The fluid-structure system is modelled by fully coupling a finite-difference representation of the structural mechanics with a boundary-element solution for the ideal-flow fluid mechanics. An Euler-Bernoulli beam is used for the 2D model and using classical thin-plate mechanics for the 3D model. Solution of the structural dynamics yields displacement, velocity and acceleration conditions that provide the boundary conditions for the flow solution while the resulting flow-perturbation pressure drives the panel's motion. The full system is cast as a single differential equation for the displacement-field of the solid-fluid interface and its time derivatives. This equation is transformed into state-space form and, assuming single-frequency response, the resulting eigenvalue problem for complex frequency is solved. In the procedure, we compute all $2N$ eigenvalues of a system discretised into N collocation points. The discretised nature of the system renders it straightforward to incorporate the types of structural inhomogeneity illustrated in Fig. 1.

3. Illustrative Results



(a) (b)

Figure 2: The variation of (non-dimensional) instability onset/recovery speeds with the magnitude of the added localised stiffening for (a) two-dimensional model (Fig. 1a) with an isolated spring, and (b) three-dimensional model (Fig. 1b) with a transverse stiffening strip.

Figures 2a and 2b respectively show typical results for the effect of adding an isolated spring (2D) and a transverse stiffening strip (3D) on the divergence-onset, divergence-recovery and flutter-onset flow speeds for water flow over an aluminium panel typical of that used for the hull of a high-speed ferry. In both cases the stiffening has been added at the panel's mid-chord because this location is the anti-node of the fundamental mode that yields the critical mode for divergence-onset of such panels. As would be expected, increasing the spring/transverse-stiffener stiffness raises the divergence-onset flow speed. However, unlimited postponement of divergence is not possible because it is seen that at a critical value of added stiffness Mode-2 divergence takes over as the critical instability. The results of the present paper will show how that a streamwise stiffening strip does not have such an inherent limitation although its effectiveness in postponing instability comes at a greater material cost.

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