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External mean flow influence on sound transmission through finite clamped double-wall sandwich panels

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ABSTRACT

This paper studies the influence of an external mean flow on the sound transmission through finite clamped double-wall sandwich panels lined with poroelastic materials. Biot's theory is employed to describe wave propagation in poroelastic materials and vari20ous configurations of coupling the poroelastic layer to the facing plates are considered. The clamped boundary of finite panels are dealt with by the modal superposition theory and the weighted residual (Garlekin) method, leading to a matrix equation solution for the sound transmission loss (STL) through the structure. The theoretical model is validated against existing theories of infinite sandwich panels with and without an external flow. The numerical results of a single incident wave show that the external mean flow has significant effects on the STL which are coupled with the clamped boundary effect dominating in the low-frequency range. The external mean flow also influences considerably the limiting incidence angle of the panel system and the effect of the incidence angle on the STL. However, the influences of the azimuthal angle and the external flow orientation are negligible.

1. Introduction

Double-wall sandwich panels have been widely used in many applications (e.g. transportation vehicles, modern buildings, and aerospace structures) due to their superior sound insulation properties over a wide frequency range and excellent mechanical properties. Poroelastic materials have been applied as the sandwich core within a double-wall (or multilayered) panel in order to improve the sound insulation performance. Based on Biot's theory [1], Bolton et al. [2] developed an analytical model for sound transmission through laterally infinite double-wall panels lined with poroelastic materials and have validated the model experimentally; this model was then extended by Liu [3] to triple-wall sandwich panels. Lee et al. [4] simplified the method of Bolton et al. by considering only the energetically dominant wave with negligible shear wave contributions and the poroelastic material was treated as a layer of equivalent fluid. Tanneau et al. [5] proposed an optimisation method for maximising sound transmission loss (STL) of infinite multilayered panels including solid, fluid and porous components, and Lee et al. [6] studied the optimal poroelastic layer sequencing using a topology optimisation method.

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The modelling of sound transmission through realistic sandwich panels, however, needs to take into account the finite nature of the structure. Brunskog [7] examined the influence of finite cavities on the sound insulation of periodically framed double-wall structures. Villot et al. [8] proposed an approximate technique based on spatial windowing of plane waves to predict sound radiation and transmission of finite multilayered structures. Leppington et al. [9] employed a modal superposition theory to model the sound transmission through a pair of rectangular elastic plates with simply supported boundary condition. Using the same method, Xin et al. [10] studied theoretically the vibroacoustic response of a clamped double-panel partition enclosing an air cavity. Xin and Lu [11] then considered both fully clamped and simply supported boundary conditions through an analytical and experimental investigation. Liu and Daudin [12,13] extended these studies to consider clamp mounted double-wall panels lined with poroelastic materials. Panneton and Atalla [14] and Sgard et al. [15] carried out numerical predictions of the STL through finite double-wall panels with poroelastic linings using finite element method and boundary element method, respectively.

In many practical applications (for example, aircraft and high-speed trains) of sandwich panels for sound insulation purposes, the presence of an external flow is common and hence its influence on sound transmission must be considered. Koval [16] found that the external flow, panel curvature and internal pressurisation affect significantly the STL of an infinite single-wall panel. Xin and Lu modelled analytically the sound transmission through a finite single panel with convective flows on both sides [17] and through an infinite double-wall panel with an external mean flow [18]. Meng et al. [19] studied this problem for infinite double-wall panels lined with acoustic absorptive materials. Zhou et al. [20] extended the work of Bolton et al. [2] to account for the external mean flow effect on the STL of double-wall panels with poroelastic linings. More recently, Liu and Sebastian [21] considered the effects of both an external and an internal mean flow on the sound transmission through double-wall sandwich panels. In addition, the similar problem for the convective effect of such an external mean flow has also been studied extensively for double-wall sandwich shells [22–28]. All these studies have shown that the presence of an external flow improves the sound insulation performance of the structures.

However, as far as sound transmission through double-wall panels is concerned, the problem considering finite dimensions, poroelastic materials, and an external mean flow has yet to be addressed theoretically, to the best knowledge of the authors. In spirit of the previous works (e.g. [11,13,20]), the present study aims to develop such a theoretical model for the sound transmission across clamp mounted finite double-wall panels lined with poroelastic materials, with a focus on the influence of an external mean flow on the STL as well as the coupled effects of the external mean flow and the clamped boundary. The remaining paper presents in Section 2 a theoretical formulation of the vibroacoustic problem. Section 3 determines the sound transmission loss and the limiting angle of incidence. The validation of the theoretical model and the numerical results on the STL, the finite extent effect and the external flow influence are discussed in detail in Section 4. The conclusions with a summary of the findings are made in Section 5.

2. Theoretical formulation

2.1. Description of the system

As illustrated in Fig. 1, the double-wall sandwich panel system consists of two parallel homogeneous thin elastic plates lined with a poroelastic layer. An air gap exists in this configuration between the poroelastic material and the facing plate. The system is situated in ambient air and a plane acoustic wave of unit amplitude is incident on the first (upper) plate and transmits through the system. The incidence field above the first plate and the transmission field underneath the second (bottom) plate are supposed to be semi-infinite. The air properties, i.e. air density and speed of sound, in the incident field, gap field and transmission field are assumed to be identical and are denoted as ρ_0 and c. The two rectangular plates are supposed to be fully clamped on each side to an infinite rigid baffle and the dimensions are a and b along the x-axis and y-axis, respectively.

In the present study, an external mean flow is considered in the incident field (see Fig. 1(b)) while the media in the air gap and the transmission side are stationary. The mean flow with the constant velocity V is assumed to be uniform in the external incident field and the boundary layer effect is ignored which is common in many simplified modelling of sound

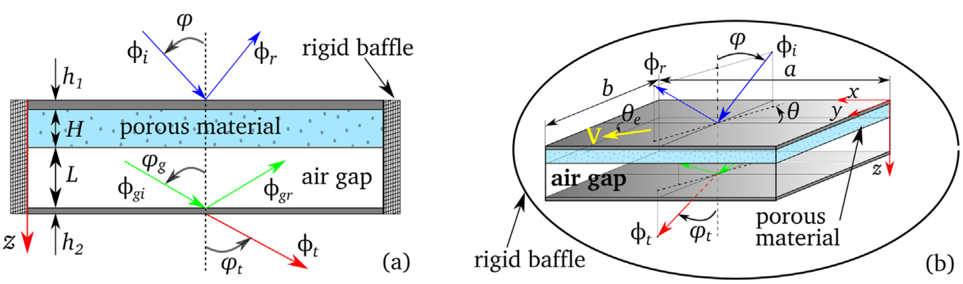

Fig. 1. Schematic diagram of sound wave transmission through the double-wall panel of the BU configuration: (a) side view, (b) perspective view.