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Influence of nature of core on vibro acoustic behavior of sandwich aerospace structures

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ABSTRACT

This paper presents the study of influence of core geometry on vibration and acoustic response characteristics of sandwich panels which are used as aerospace structures. Sandwich panels considered in this research work are: (a) Honeycomb core, (b) Truss and Z core, (c) Foam core. The present study has found that (i) For a honeycomb core sandwich panel in due consideration to space constraint, the better acoustic comfort can be achieved by reducing the core height and increasing the face sheet thickness. (ii) It is demonstrated that, for a honeycomb core sandwich panel, vibration and acoustic response is not sensitive to the cell size. (iii) It is observed that, triangular core gives better acoustic comfort for the truss core sandwich panel compared to other type of core. (iv) For foam core sandwich panels, it is observed that sandwich panel with carbon-epoxy (high stiffness) face sheet radiates less sound in the lower frequency range (0–100 Hz). While the sandwich panel with Titanium (high density) face sheet radiates less sound at the higher frequencies. In order to reduce the preprocessing time and computational effort throughout the analysis in the present study, equivalent 2D elastic properties are calculated and used to find out the vibration and acoustic response characteristics.

1. Introduction

Sandwich panels are most commonly used as structural member in aerospace industries due to their high stiffness to weight ratio compared to conventional metallic and laminated composite structural members. The property of high stiffness to weight ratio leads to efficient transmission and radiation of acoustic noise [1]. Mellert et al. [2] studied experimentally the impact of sound and vibration on health, travel comfort and performance of flight attendants and pilots. Their results revealed that noise level has significant effect on various symptoms and health indices, especially when the level increases with time of work. Sandwich panel is made up of stiff top and bottom layer separated by a relatively soft core. The core can be of any material or architecture but four types are most generally used namely: (a) truss or corrugated core, (b) web core, (c) foam or solid core, (d) honeycomb core as shown in Fig. 1 for the above said applications [3].

Polymeric foam core has been replaced by aluminium sandwich structures with honey comb core and foam core [4,5]. The fuselage structure of passenger aircraft along with its mechanical duties has also to protect passengers against excessive noise and thermal constraints in the different flight phases [6]. A fuselage section analysed by Tooren and Krakers [6] consists of a 'Z' and 'C' stiffened sandwich panels. They optimised the stiffened structures for minimum weight subjected to mechanical, acoustical and thermal constraints.

Sandwich panels are complex three dimensional thin walled structures for which numerical method is the most commonly employed method to analyse the dynamic behaviour of thin walled sandwich panels with different types of core geometries [7]. In order to analyse a sandwich panel numerically, both three dimensional finite element model (FEM) and its equivalent two dimensional FEM can be used. There are three ways to model a sandwich panel: (i) full solid modelling, (ii) shell modelling, and (iii) mixed modelling [8]. So, it is very important to select carefully which element to use. A 3D model requires high pre-processing time, is highly expensive and also it often leads to numerical ill conditioning [9]. Whereas a sandwich structure analysed by using its equivalent 2D FEM model avoids high preprocessing time and reduces numerical error to a greater extent [8]. Over all, the computational effort is significantly reduced when using the equivalent 2D FEM model [8]. Accuracy of the results obtained in a commercial FE software greatly depends on the equivalent elastic constants

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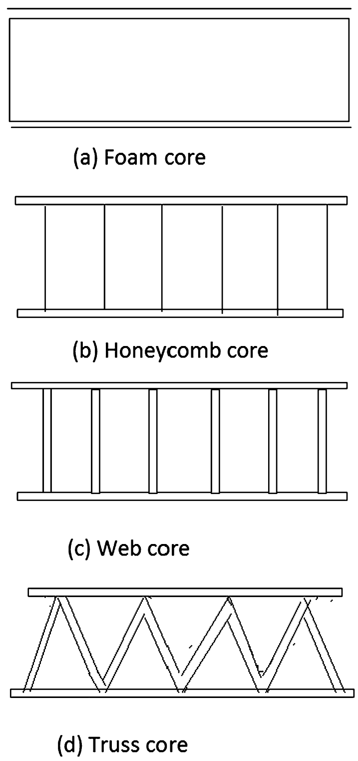

Fig. 1. Types of sandwich construction with different kinds of core [3].

used. Libove and Hubka [10] derived the elastic constants for sandwich panels with a continuous corrugated core. Lok and Cheng [11] derived the equivalent elastic properties of a truss core sandwich panel and compared the maximum deflection for cellular, trapezoid and triangular core with zed core and corrugated core sandwich panels using 2D model and verified the result with 3D model. Fung et al. [12] presented elastic properties of z-core sandwich panel by comparing the behaviour of a unit z-core sandwich panel with that of a thick plate. Lok and Cheng [13] investigated the free vibration of clamped truss core sandwich panel. They have used equivalent stiffness properties of the sandwich panel, to find out the free and forced vibration response. The honeycomb sandwich plate is applied widely in the modern spacecraft structure design [14]. Boudjemai et al. [15] performed a numerical study on free vibration response of honeycomb panels used in the satellites structural design. They also analysed the effect of its design parameters using equivalent plate theory.

Prediction of sound radiation characteristics of thin walled structures is an important aspect in the structures design phase in order to keep the acoustic behavior in a desirable level. To calculate the sound radiation characteristics of flat structural panel like members the Rayleigh integral method is generally used. It is superior to the simple source method as its accuracy is virtually unaffected by the nature of the integrand [16]. Chao et al. [17] proved that the technique of using added-on honeycomb stiffened structure is effective in the noise transmission loss. Honeycomb in its back cavity has good sound absorption characteristics [18]. Sargianis et al. [19] investigated the effect of core thickness change on the vibrational properties of Rohacell foam/carbon fibre face sheet sandwich composite beams. Sargianis et al. [19] studied the effect of core material on wave number and vibration damping characteristics in carbon fibre sandwich composites to investigate acoustic performance. Petrone et al. [1] measured the radiated acoustic power from the aluminium foam sandwich panel on the upper face sheet of the sandwich panels subjected to a point excitation applied on the other face of the panel. They calculated the acoustic power by measuring the sound intensity in direction perpendicular to the panel.

The impact of sound and vibration on health, travel comfort and performance of flight attendants and pilots has significant effect. Hence, it is necessary to design a sandwich panel with acoustic comfort. But a design which involves the acoustic comfort is always dense and large in size than the design considering only mechanical strength. This drawback can be overcome by exploring the influence of core geometry on vibration and acoustic response of sandwich panel. In this aspect, the present work focuses on the study of influence of core geometry on vibration and acoustic response characteristics of sandwich panels which are used as aerospace structures.

In this present work, the sound power radiation of generally used cores such as honeycomb, triangular, trapezoidal, cellular, zed, aluminium foam and Rohacell foam with aluminium, titanium and epoxy carbon laminate face sheet is analysed based on equivalent 2D FEM model. In section 1, vibration and acoustic response of honeycomb core is analysed and the effect of its design parameters is studied. In section 2, vibration and acoustic response of different topology of truss core sandwich panel is analysed and compared with zed core. In section 3, vibration and acoustic response of aluminium foam and different types of face sheet with Rohacell foam core sandwich panel is analysed and compared.

2. Methodology

The free and forced vibration response of the sandwich panel is analysed using FEM based on 2D model with equivalent elastic properties and its response is given as an input to Rayleigh integral in order to obtain the sound radiation characteristics.

To start with,

(i) Firstly, the equivalent stiffness (bending stiffness, twisting stiffness and transverse shear stiffness) properties of the sandwich panel are found and by using these values, the sandwich panel is equalised as an orthotropic plate. It is referred as an equivalent 2D model, having same stiffness's of the sandwich panel. For an orthotropic plate with height 'h' its stiffness's can be calculated as

$$D_x = \frac{E_x h^3}{12};\ D_y = \frac{E_y h^3}{12};\ D_{xy} = \frac{G_{xy} h^3}{6};$$
$$D_{Qx} = k^2 G_{xz} h;\ D_{Qy} = k^2 G_{yz} h \tag{1}$$

where, D_x and D_y are bending stiffness's, D_{xy} is twisting stiffness, and D_{Qx} and D_{Qy} are the transverse shear stiffness's, E_x and E_y are the Young's modulus and G_{xy}, G_{xz}, G_{yz}, are the shear modulus, k^2 is the transverse shear correction factor.

(ii) Secondly, for CCCC boundary condition the natural frequencies and mode shapes of the equivalent 2D model are found by solving the eigenvalue problem as given below:

$$[K - \omega_k^2 M]\{\phi_k\} = 0 \tag{2}$$

where, K is the structural stiffness matrix, M is the structural mass matrix, while ω_k is the circular natural frequency of the sandwich panel and ϕ_k is the corresponding mode shape.

(iii) After computing the natural frequencies and mode shapes, the vibration response of the sandwich panel is found using the harmonic response analysis. The general equation of motion for a sandwich structure is given below

$$M\ddot{U} + C\dot{U} + KU = F(t) \tag{3}$$

where, C is the damping matrix, $F(t)$ the applied load vector (assumed time-harmonic), $\ddot{U}$, $\dot{U}$ and U are the acceleration,