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Vibroacoustic behavior of orthotropic aerospace composite structure in the subsonic flow considering the Third order Shear Deformation Theory

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ABSTRACT

An analytical model is performed across the aerospace composite structure to interpret acoustic transmission of the infinitely long doubly curved shell considering the effect of mean flow with the aid of Higher-order Shear Deformation Theory (HSDT). Accordingly, the displacements are extended up to cubic order of thickness coordinate based on Third-order Shear Deformation Theory (TSDT) known as HSDT including no effect of shear correction factor. Consequently, in order to present the Sound Transmission Loss (STL) of the present model, the excitation of the structure with an oblique plane sound wave is set in order. However, the acoustic transmission is performed by incorporating the both of shell equations and acoustic wave equations, simultaneously. In the next step, the accuracy as well as the reliability of the present model is provided by comparing the achieved results with those available in literature. Moreover, the present results illustrate the importance of investigating TSDT due to clarifying the more precise outcomes. Finally, the importance of the present model is cleared as a result of improving the mechanical and sound insulation properties particularly in low frequency zone by illustrating the STL comparison between the current structure and those structures without any curvature.

1. Introduction

It is a popular custom in many fields of engineering industries containing aerospace, high-speed train, marine and automotive structures to use composite doubly curved shell as a fuselage skin, as a result of high capacity in bearing the external loads. In addition, the shells made of composite material due to their higher strength and stiffness to weight ratio, have been extensively employed in many various technical applications. Besides, it is noteworthy that a designer can tailor various properties to provide a specific application by working on thickness, and material type. Perhaps, the more decisive assumption is to utilize the public shell equations straightly as a doubly curved shell. As another consequence, these shells are utilized for the both of open and deep shells. However, they include various types of curvature and also Plan form such as closed cylindrical shell or sometimes are known as a curved plate.

Although the deep shells are supported by many theories, this issue for doubly curved shells is restricted. In fact, Classical Shell Theory (CST) is applied for the thin shells. While the effects of the shear deformation and rotary inertia become more important in the relatively thick shells, First-order Shear Deformation Theory (FSDT) is utilized. Note that the both of CST and FSDT are known as the simplest equivalent single-layer theories so that they can describe the kinematic behavior of the most laminates in thin as well as relatively thick shells. However, by thickening the shell, the importance of employing the theory which can interpret the kinematic behavior of the structure more precisely, is remarked. In this situation, TSDT is assigned as a result of presenting the more precise interlaminar stress distribution. However, since this theory contains of higher-order stress resultants which are hard to describe physically, therefore applying this theory for the thick shell is unavoidable. Accordingly, in the present formulation, the simple form of HSDT known as Third-order Shear Deformation Theory (TSDT) is employed with expanding the displacements up to the three order of the thickness coordinate to express the influences of the transverse shear stress as well as transverse shear strain through each layer.

Sound Transmission Loss (STL) is a design factor for the sound power reduction which has the main role in the noise control branch through various structures including cylindrical shell as well as plate. Herewith, the study of acoustic behavior into such

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structures has been considerably extended in several publications since 60 years ago. Accordingly, some authors conducted their attention across the acoustic analysis of the plate. Likewise, the geometrical properties of the finite plate backed by cavity or without one were taken into account by Bhattachary et al. [1]. In an analytical model proposed by Koval [2], the effects of external air flow, internal fuselage pressurization and panel curvature on power transmission of the single walled panel were presented. Leissa [3] suggested a theoretical model by investigating the effect of shear deformation across the laminated composite curved panels. In another work presented by Wu et al. [4], the dynamic response and the acoustic analysis of the finite baffled plate due to exciting the structure by a turbulent boundary layer was performed. Frampton et al. [5] proposed an analytical model on elastic plate impinged upon full potential flow and random pressure field by considering the further effect of external flow. Besides, the singular value decomposition as well as Galerkin's method was applied in another work [6] to model the problem based on considering the convected fluid load. Xin et al. [7] presented a theoretical model across the finite panel in the convected fluid based on considering modal superposition method. Afterwards, Chronopoulos et al. [8] determined the thermal effect on power transmission through the composite panel in different temperatures. In another work [9], the influence of incorporating the core material as an intermediate layer including honeycomb, truss and foam on acoustic behavior of the sandwich panel was presented.

In the following, literature review is presented on power transmission through circular cylindrical shell due to various applications in different parts of engineering and aerospace structures. Accordingly, Foxwell et al. [10] conducted their attention through the vibration of a thin-walled stiffened cylinder in an acoustic field. Besides, various research works on the acoustic analysis of the isotropic, orthotropic and laminated composite cylindrical shell could be found in Koval [11–13]. Consequently, Tang et al. [14,15] extended the last works across the thick and thin shells to calculate the STL through the infinite cylindrical sandwich shells impinged upon an oblique plane sound wave considering two various angles of incidence as well as various fluids in the outside and inside of the shell. As another aspect, Lee et al. [16] measured the power transmission of the thin isotropic cylindrical shell and then employed Love's equations to derive the vibration of cylindrical shell in all three displacements fields. As obviously defined in literature, the importance of employing laminated composite shells in industry date back to 1962 in Ambartsumian's work [17] without presenting any vibration results. Accordingly, Ghinet et al. [18] compared two models of the laminated composite shell so that in the first one the displacement field was determined to model a symmetric structure. However, in the second one a discrete thick laminated composite cylindrical shell was modeled by employing the equation of motion as well as displacement field for each layer. In the following, Daneshjou et al. [19–21] presented the power transmission across the various kinds of the orthotropic and sandwich structures including damping layers for reducing noise and vibration. Besides, they applied TSDT in another work [22] to designate the acoustic transmission across the FGM cylindrical shell. Next, Chandra et al. [23] conducted their regard for the acoustic analysis of the Functionally Graded plate considering FSDT. In another work, higher order shear deformation theory was employed by Cao et al. [24] to determine the acoustic analysis of the cylindrical shell. Rajabi et al. [25] considered the scattering of the acoustic wave with arbitrary angle as well as arbitrary thick helically filament across cylindrical shell considering the laminated approximation procedure. Consequently, Tsai et al. [26] employed thick plate theory to achieve the wave transmission through N-layer composite plate considering the conjugate gradient optimization method. Recently, Talebitooti et al. [27–29] offered three model of power transmission across the STL of the laminated composite cylindrical shell. Likewise, in the first model, vibroacoustic analysis of STL through composite structure in the presence of external flow was presented considering higher order shear deformation theory. Then, genetic algorithm was taken into account to optimize the sound transmission of the double-walled composite structure along with porous material. They have also employed 3D elasticity theory to calculate the STL of the double-walled laminated composite cylindrical shell interlayered with an air-gap insulation.

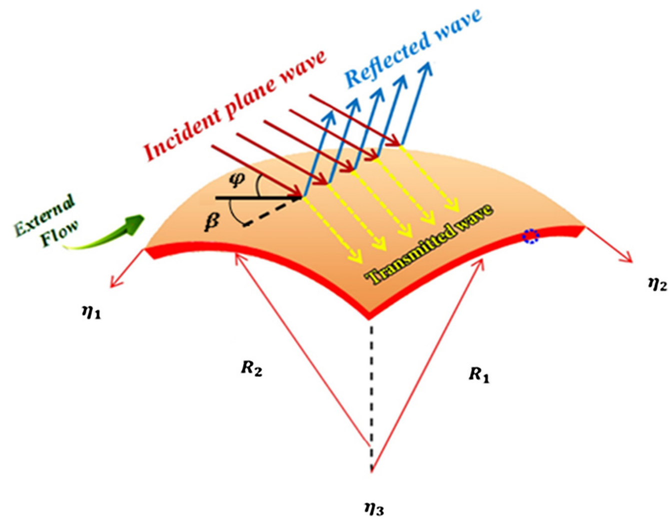

Fig. 1. Schematic diagram of orthotropic doubly-curved shell made of Graphite/Epoxy in the mean flow under excitation of a plane sound wave with two angles of incidence φ and β.

According to the literature, the acoustic transmission problem has been extensively investigated considering various types of the structures including cylindrical shell and plate. However, the leakage of research work through the acoustic analysis of doubly curved shell as a result of different technical applications is considerably concerned. This issue excited the authors to consider Third-order Shear Deformation Theory (TSDT) by enlarging the displacement filed up to cubic order of thickness coordinate through the infinitely long doubly curved shell to designate what combination of the wave transmission results in sound insulation. Accordingly, in the first step, the vibration equations of the shell are combined with those of acoustic wave equations, simultaneously. Next, the vibroacoustic behavior due to excitation of an oblique plane sound wave is designated. Consequently, some verifications are presented with comparing the obtained results with those available in literature. This paper also includes a comparison between the shells with curvature in comparison with the one without curvature. It is well demonstrating the improvement of the STL for the curved shell particularly in low frequency domain. Finally, the obtained results from the current study perfectly clarify the importance of employing higher order shear deformation theory in representing the precise results in thick shells.

2. Formulation

2.1. System description

The inspection of Fig. 1 illustrates, an infinitely long orthotropic doubly curved shell with radiuses R_1 and R_2 in η_1 and η_2 directions, wall thickness h, and mass density of the shell ρ, goes under excitation of a plane sound wave with two angles φ and β in the presence of uniform airflow with constant velocity V, in which φ denotes the angle between wave and horizontal plane and β is specified as the clockwise angle from the projection of wave on