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Acoustic transmission through laminated composite cylindrical shell employing Third order Shear Deformation Theory in the presence of subsonic flow

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ABSTRACT

In this paper acoustic behavior of the laminated composite cylindrical shell, excited by an oblique plane sound wave, is investigated. The cylindrical shell is assumed to be infinitely long with uniform airflow in the external fluid medium. To provide an analytical solution of Sound Transmission Loss (STL) based on Third-order Shear Deformation Theory (TSDT), the displacements are developed as the cubic order of the thickness coordinate. Furthermore, the equations of wave propagation are expanded to determine STL beside vibration equations of laminated composite cylindrical shell, simultaneously. Then, the obtained result is compared with that of previous models. However, the importance of using Third-order Shear Deformation Theory (TSDT) reveals the fact that the present model demonstrates more accurate results, particularly for thick shell where the effects of the shear and rotation become more significant in lower R/h. Moreover, with changing the R/h ratios, the difference between the present study (TSDT) and other shell theory such as First-order Shear Deformation Theory (FSDT) is increased. Eventually, numerical results are discussed to indicate the effectiveness of different structural properties and geometrical properties on STL.

1. Introduction

The applications of laminated composite shell in the last decades have been extensively increased, as a result of advantages offered by a high strength to weight ratio. Among these applications, the significance of employing cylindrical shell and panel have been absorbed the researcher attention, particularly in the aerospace industries which can be extremely found in helicopters, aircrafts, engine cowling and launch vehicles. It is noteworthy that the vibration of the outer shell of the fuselage during the flight may be amplified. Consequently, this vibration is transmitted to the interior and can generate a high-level noise within the cabin. Therefore, the reduction of this disturbance into such structure is extensively attempted. Hence, the investigation of sound transmission through the laminated composite shell is unavoidable.

Significant inspections of laminated composite shells date back to 1962 when Ambartsumian [1] conducted his research's work in composite shell. Although, it does not contain any vibration result but it was well-known as a useful source for laminated composite shell. Librescu [2,3] developed his work on the basic flutter and aero elasticity and also such structural components were discussed. Classical shell theories were extended by Leissa [4] on the basis that the most of them produce similar results; the exceptions were the membrane and Donnell–Mushtari theories, which is arranged as a shallow shell theory. When the application of Ritz method was revealed for twisted plates, energy functional was applied by Leissa [5] directly for isotropic shells. Consequently, the last theories were extended and the application of this theory was presented for laminated composite shells. Besides, in another work [6] the influence of shear deformation was taken into account through the laminated composite curved panels. Smith [7] for the first time measured noise transmission, by Sound Transmission Loss (STL). In fact, he proposed a theoretical study through a thin, isotropic cylindrical shell by considering only inward traveling wave. It should be considered that in this work the STL was defined as a ratio of absorbed power to incident power. When the importance of ring frequency and coincidence frequency was revealed, an analytical model of STL was provided by White [8] through the cylindrical shell. Koval [9,10] suggested mathematical models of STL through the infinite shell by utilizing displacement field and taking account the effects of membrane and bending in deriva-

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tion. Alongside, he [11] developed his previous work on the STL of the laminated composite infinite cylindrical shell impinged upon plane sound wave by neglecting the effects of the shear and rotation. Afterwards, Koval's research work was extended by Blaise et al. [12] on multi-layered laminated composite orthotropic cylindrical shells, considering two independent incident angles. Consequently, the numerical result was compared with Koval and some numerical errors were presented. Tang et al. [13] utilized First-order Shell Theory for thick shell to achieve STL through the infinite cylindrical sandwich shell excited by a plane sound wave. Lee and Kim [14] conducted their regards on analytical and experimental models by considering all three displacement fields, for studding the sound transmission through the infinitely large circular cylindrical shell. As another consequence, Love's equation was used for shell vibration motion and inside cavity was assumed to be anechoic. Later, the STL coefficient of the two models of laminated composite cylindrical shell was compared with each other by Ghinet et al. [15] on the basis that the first model involved a symmetrical laminate composite shell, by considering that the displacement field was developed globally in the thickness direction and the other one described a discrete thick shell where the equations of motion beside the displacement field were discretized for each layer. Furthermore, it should be noted that the displacement field was achieved by using the Mindlin theory. When the applications of the circular thin orthotropic shells were revealed in the aerospace industry, Daneshjou et al. [16] extended the last works through orthotropic cylindrical shells by considering the effects of subsonic external flow. As another consequence, their results were compared with the Classical thin Shell Theory. By increasing awareness of this subject that structure with damping layers are applicable for reducing noise and vibration, especially in polymeric materials, Daneshjou et al. [17] conducted their attentions to understand the STL characteristics of the shell with a free layer damping treatment. In following, they [18] applied porous layer as a core material in another paper on the laminated composite double-walled shell by using Classical Shell Theory. An analytical model of STL was developed by Zhou et al. [19] through a double shell lined with poroelastic material including the effect of external flow. The Classical Shell Theory was used for the inner and outer skins whereas an equivalent fluid method based on Biot's Theory was applied for the core porous layer. In most of the literature survived above Classical Shell Theory (CST) was used to model the shell vibration. As it's obvious, the only thin shell is supported by this theory. But, it should be noted that, when the effects of the shear deformation and rotary inertia, especially for thick shell become important, using CST can cause remarkable errors in such case. According to this matter, First-order Shear Deformation Theory (FSDT) was applied by Daneshjou et al. [20] to study STL through laminated composite cylindrical shells by considering transverse shear deformation. In fact, all three displacements of the shell were considered to show the effects of shear and rotation in higher frequencies. After many years, they also proposed a theoretical model of STL through relatively thick FGM cylindrical shell by using Third-order Shear Deformation Theory (TSDT). The considerable achievement of their work [21] was taking account of the effects of the shear and rotation terms; particularly in lower R/h ratio, the accurate results were obtained from TSDT. In the research work done by Chandra et al. [22], Vibro-acoustic analysis of STL through FGM plates was developed by using FSDT. Later, an analytical model was offered by Talebitooti et al. [23] through an orthotropic cylindrical shell. As another consequence, the shell has been immersed in a fluid medium with an external airflow. In this research's work the displacements were developed as the cubic order of the thickness to determine an analytical solution based on Third-order Shear Deformation Theory. Furthermore, the exact solution was applied by solving cylindrical shell vibration equation besides acoustic wave equation, simultaneously. Magniez et al. [24] developed an analytical model to obtain sound transmission employing FSDT through infinite multilayer cylinder consists of orthotropic skins and an isotropic polymer core. It should be noted that elasticity theory was applied to determine the motion of the isotropic thick polymer core. In following, they [25] utilized FSDT to analyze a sandwich cylindrical shell lined with a poroelastic core, whereas the motion of the poroelastic core was defined with the full 3D Biot's theory. Liu et al. [26] suggested a theoretical study on the STL of the double-walled cylindrical shell sandwiching a layer of porous material as well as considering further influence of the external mean flow. Moreover, their results were compared with Zhou to illustrate some errors in the derivations and the numerical code in Zhou's study. Talebitooti et al. [27] proposed three-dimensional elasticity model of wave propagation to obtain STL through orthotropic cylindrical shells considering the state space method. They assumed the shell is infinitely long and the external excitation is performed by an oblique plane sound wave with a uniform airflow in the external fluid medium. They indicated that the 3D elasticity theory demonstrates more accurate results, particularly for thick shell where the effects of the shear and rotation become more significant in lower R/h. Just recently, STL was investigated [28] through thick-walled cylindrical shell employing 3D elasticity theory. They were shown that CST and higher order shell theories does not have enough accuracies especially at high frequencies, as a result of increasing rotational terms. Following the previous work, another paper [29] was made on double-walled cylindrical shell consists of isotropic skins and poroelastic core. It is noteworthy to mention that the Extended Full method (EFM) was taken into account to analyze the equation of motion.

Sivadas et al. [30] analyzed vibration of the laminated conical shells with variable thickness using finite element method as well as considering Love's approximation thin shell theory for solving the problem. In this paper also the effects of the variation parameters such number of the layers and thickness of the shell on the lowest natural frequency were analyzed. It should be considered that the procedure was followed by keeping constant the mass of the shell to present useful example of the influence of the thickness distribution on the natural frequency. In following, Wu et al. [31] applied differential quadrature to present free vibration analysis of the laminated conical shells with variable stiffness. Then, First-order Shear Deformation Theory (FSDT) was taken into account to reveal the effects of the transverse shear deformations. Besides, the boundary conditions were substituted by a system of algebraic equations. It is also necessary to note that in this research work, the discrepancies between the analyses of the laminated shells are determined by taking account constant and variable stiffness. After many years, Civalek [32] conducted his attention to propose numerical analysis of free vibration of laminated composite cylindrical as well as conical shells employing discrete singular convolution (DSC). As another consequence, the obtained results were presented graphically for various material and geometric parameters as well as considering the influences of the number of layers and the circumferential wave number on frequencies characteristics.

In most of the last analytical and experimental models, STL was presented and discussed through the isotropic, orthotropic and FGM circular cylindrical shells. Furthermore, most of the literature survived above, indicates that no study has been done to determine STL through the laminated composite cylindrical shells by using TSDT, so far. Therefore, in this paper the TSDT is utilized in deriving the cylindrical shell motions by expanding the displacements as a cubic order of the thickness coordinate. Moreover, with considering the equations of solid-fluid interactions the governing Vibro-acoustic equations are derived. Eventually, in order to inves-