氏　　　　名	サハラト チャンタヌマアポン　チャンタヌマアポン ＳＡＨＡＲＡＴ　CHANTHANUMATAPORN
所　　　　属	システムデザイン研究科　システムデザイン専攻
学位の種類	博士（工学）
学位記番号	シス博　第96号
学位授与の日付	平成29年9月22日
課程・論文の別	学位規則第４条第１項該当
学位論文題名	Vibration Characteristic of Lightweight Sandwich Structure Interacting with Ambient Air (周囲空気と相互作用する軽量サンドイッチ構造の振動特性)
論文審査委員	主査　教授　　渡辺　直行 委員　教授　　北薗　幸一 委員　教授　　佐原　宏典 委員　准教授　稲澤　歩

【論文の内容の要旨】

Nowadays, sandwich structures are extensively accepted in advance engineering applications (e.g., aeronautics, automobiles, marines, and buildings) because of their excellent strength-to-weight ratio, which results in significant weight reduction and efficiency improvement. For the application of solar panels in artificial satellites, the extremely lightweight sandwich panels are employed as the main structure. In addition, the solar panels are generally arranged in folded configuration during launching and they are therefore inevitable to couple with air layer presenting between the panels. However, the influence of ambient air layer is very significant because it can alter the dynamic behaviors of the lightweight structure. Therefore, the vibration analysis of extremely lightweight sandwich structures requires the consideration of ambient air effect. Besides, for the case of thin air layer, the air viscosity effect must be taken into account. This thesis aims to investigate experimentally and numerically the influence of ambient air layer on the vibration of an extremely lightweight sandwich panel.

The background, literature reviews, problem statements, objectives, and overview of this dissertation are presented in Chapter 1. Literature study on the vibration of sandwich structures is provided and various analysis models for describing the bending vibration are clarified. Literature reviews on the influence of the ambient air on the vibration of sandwich structures are presented. Until now, there are a

few researches focusing on the vibration of sandwich panel coupled with air. Some reviewed works performed the experimental investigation for studying the effect of ambient air but the influence of air layer thickness was not considered. In regard to the numerical analysis, a few models are proposed. The available models simply focused on the configuration of single air layer and constant pressure across the layer thickness. In addition, the sandwich structures were simply modeled as a homogeneous structure and their thickness were not included into the boundary condition of mesh model. Objectives of this thesis are to fulfill the current deficiency, by developing an experimental modal testing with the feature of simulating air layers around the sandwich panel; formulating a suitable analytical model for studying free vibration of sandwich panel coupled with ambient air layer; and investigating the influence of ambient air layer in various aspects.

The detail of experimental setup and the effect of ambient air layer on the fundamental natural frequency of a honeycomb sandwich panel are described in Chapter 2. The experimental setup based on modal testing was proposed with the feature of simulating air layer around the sandwich panel. The thickness of air layer can be varied from thick to thin. To clearly clarify the effect of ambient air layer thickness, 15 conditions of air layer thickness were determined for performing modal testing. The results show that the ambient air layer disturbs the vibration of sandwich panel as an added mass effect resulting in the reduction of natural frequency. In addition the effect becomes stronger as GAP (the thickness of air layer between the panel face and the rigid wall) becomes thinner. As compared with the natural frequency without air effect, the natural frequency decreases of 65, 73, and 80 % for the condition of GAP of 10, 6, and 3 mm, respectively.

The concept and finite element formulation for analyzing free vibration of a sandwich panel coupled with ambient air are presented in Chapter 3. The model configuration is a vibrating flexible sandwich panel coupled with ambient air surrounded by rigid walls. The flexural vibration of the sandwich panel was described by the governing equation formulated on the basis of sandwich theory. For the air domain, the assumption of viscous incompressible flow was employed because the air viscosity effect is important for the thin air layer condition. The penalty function method was applied for the formulation of the Navier-Stokes equations system to minimize the computational time and effort. The governing equations were derived in the weak-form representation and then a set of discrete matrix equations based on the methods of Galerkin weight residual and finite element. The discrete matrix forms were formulated in a single eigenvalue equation. The implementation of finite element model is also provided in Chapter 3. The types of element for discretizing the panel and air domain as well as the integral scheme are explained. The finite element mesh models including and excluding the panel thickness are illustrated.

The parametric studies and discussions are presented in Chapter 4. In addition, the validation of the finite element model was examined by investigating the convergence of the obtained results and comparing the results with the experimental results and other analytical solutions. The results show good convergence and good agreement with the experimental results and analytical solutions. The influences of shear deformation and ambient air on the natural frequencies of three honeycomb sandwich panels were studied. The shear modulus of sandwich core, the thickness of sandwich core, the thickness of face sheets were varied to clarify the significance of considering the shear deformation effect for studying the bending vibration of sandwich panels. The results show the importance of considering the shear deformation effect especially for the case of weak core and/or thick panel. In order to demonstrate the degree of ambient air effect, the parametric studies on the air layer thickness, viscosity, and density as well as the panel length, bending stiffness, mass density, and thickness were conducted. The results show that the degree of ambient air effect is magnified when the air layer becomes thinner; the panel density decreases; and the panel length increases.

The thesis is concluded in Chapter 5. In addition, the recommendations for future research are summarized in this chapter. It can be concluded that the consideration of ambient air effect is very important for the vibration analysis of extremely lightweight sandwich structures. Especially for the case of thin ambient air layer, the natural frequency decreases of 80 % as compared with the natural frequency without air effect. The good agreement between the experimental and numerical results indicates that the influence of air becomes stronger when the air layer becomes thinner. In addition, the proposed analysis model demonstrates the capabilities for analyzing vibration characteristic of a sandwich panel coupled with ambient air in various conditions.