

# Aerothermoacoustic Response of Shape Memory Alloy Hybrid Composite Panels

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**Supersonic nonlinear vibrations of a traditional composite panel impregnated with prestrained shape memory alloy fibers and subjected to combined aerodynamic, thermal, and random acoustic loads are investigated. A nonlinear finite element model is developed using the first-order shear-deformable plate theory, von Kármán strain-displacement relations, and the principle of virtual work. The aerodynamic pressure is modeled using the quasi-steady first-order piston theory. Thermal load is assumed to be steady-state constant temperature distribution, and the acoustic excitation is considered to be a white-Gaussian random pressure with zero mean and uniform magnitude over the panel surface. Nonlinear temperature-dependence of material properties is considered in the formulation. The dynamic nonlinear equations of motion are transformed to modal coordinates to reduce the computational efforts. The Newton–Raphson iteration method is employed to obtain the dynamic response at each time step of the Newmark numerical integration scheme. Finally, the nonlinear response of a shape memory alloy hybrid composite panel is presented, illustrating the effect of shape memory alloy fiber embeddings, aerodynamic pressure, sound pressure level, and temperature rise on the panel response.**

## I. Introduction

**T**HIN plates are a commonly used form of structural components, especially in aerospace vehicles, such as high-speed aircraft, rockets, and spacecraft, which are subjected to aerodynamic loads, thermal loads due to aerodynamic and/or solar radiation heating, and random acoustic loads due to engine and/or aerodynamic transonic noise. This results in temperature and pressure distributions over the panel surface. The presence of these thermal and pressure fields results in a flutter motion at a lower aerodynamic pressure, or a larger flutter limit-cycle amplitude at the same aerodynamic pressure. In addition, a high-temperature rise may cause large thermal deflections (thermal buckling) of the skin panels, which could affect flutter response. Accordingly, it is important to consider the interactive effect of aerodynamic, thermal, and random acoustic loads.

Panel flutter is a phenomenon that is usually accompanied by temperature elevation on the outer skin of high-speed air vehicles. Panel flutter is a self-excited oscillation of a plate or shell in supersonic flow. Because of aerodynamic pressure forces on the panel, two eigenmodes of the structure merge and lead to this dynamic instability. Panel flutter differs from wing flutter only in that

the aerodynamic force resulting from the air flow acts only on one side of the panel. Most flutter analyses can be placed in one of four categories based on the structural and aerodynamic theories employed: 1) linear structural theory; quasi-steady aerodynamic theory, 2) linear structural theory; full linearized (inviscid, potential) aerodynamic theory, 3) nonlinear structural theory; quasi-steady aerodynamic theory, or 4) nonlinear structural theory; linearized (inviscid, potential) aerodynamic theory. Analyses of the first type have two major weaknesses: a) it does not account for structural nonlinearities, hence it can only determine the flutter boundary and can give no information about the flutter amplitudes, and b) the use of quasi-steady aerodynamics neglects the three-dimensionality and unsteadiness of the flow, hence it cannot be used in the transonic region where the flutter is most likely to occur. Analyses of the second type are intended to remedy weakness b, but this type still has weakness a. The third type remedies weakness a, but still possesses weakness b. The fourth type remedies both weakness a and b [1]. Mei et al. [2] provided a review on the various analytical methods and experimental results of supersonic and hypersonic panel flutter. An eigenvalue solution was developed by Dixon and Mei [3] for the nonlinear flutter analysis of thin composite panels using a linearized updated mode with nonlinear time function approximation. Xue and Mei [4] presented an incremental finite element frequency-domain solution for the nonlinear flutter response of thin isotropic panels under combined thermal and aerodynamic loads. Liaw [5] studied the nonlinear supersonic flutter of thin laminated composite plate structures subjected to thermal loads. Abdel-Motagaly et al. [6] investigated the effect of flow direction on the flutter limit-cycle amplitude of thick composite panels.

The surface panels of advanced high-speed aircraft and spacecraft may exhibit large random vibration under high acoustic loads, and may possibly experience both random vibration and aerodynamic flutter at elevated temperatures. Both of these effects are nonlinear in nature, and their combined response can lead to difficulties in the prediction fatigue life. A literature review on the nonlinear response and sonic fatigue of surface panels was presented by Vaicaitis [7].

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