Mechanical Systems and Signal Processing 79 (2016) 99–111

Contents lists available at ScienceDirect

Mechanical Systems and Signal Processing

journal homepage: www.elsevier.com/locate/ymssp

Flutter suppression of plates using passive constrained viscoelastic layers

A.G. Cunha-Filho [a], A.M.G. de Lima [a,*], M.V. Donadon [b], L.S. Leão [a]

[a] Federal University of Uberlândia-School of Mechanical Engineering, Campus Santa Mônica – P. O. Box 593, CEP 38400-902 Uberlândia, MG, Brazil
[b] Technological Institute of Aeronautics, São José dos Campos, SP 12228-900, Brazil

ARTICLE INFO

Article history:
Received 12 February 2016
Accepted 20 February 2016
Available online 5 March 2016

Keywords:
Flutter suppression
Viscoelastic materials
PASSIVE control
Finite element

ABSTRACT

Flutter in aeronautical panels is a self-excited aeroelastic phenomenon which occurs during supersonic flights due to dynamic instability of inertia, elastic and aerodynamic forces of the system. In the flutter condition, when the critical aerodynamic pressure is reached, the vibration amplitudes of the panel become dynamically unstable and increase exponentially with time, significantly affecting the fatigue life of the existing aeronautical components. Thus, in this paper, the interest is to investigate the possibility reducing the effects of the supersonic aeroelastic instability of rectangular plates by applying passive constrained viscoelastic layers. The rationale for such study is the fact that as the addition of viscoelastic materials provides decreased vibration amplitudes it becomes important to quantify the suppression of plate flutter coalescence modes that can be obtained. Moreover, despite the fact that much research on the suppression of panel flutter has been carried out by using passive, semi-active and active control techniques, few works have been proposed to deal with the problem of predicting the flutter boundary of aero-viscoelastic systems, since they must conveniently account for the frequency- and temperature-dependent behavior of the viscoelastic material. After the presentation of the theoretical foundations of the methodology, the description of a numerical study on the flutter analysis of a three-layer sandwich plate is addressed.

1. Introduction

The aeronautical panel flutter phenomenon is an important problem to be investigated during the analysis and design of aerospace vehicles. It is a self-excited oscillation normally occurred during supersonic flights due to the dynamic instability of inertia, elastic and inertial forces of the system [1–3]. As the speed of the air flowing over one side of the panel increases, the movement of the panel itself leads to a significant variation of the aerodynamic pressure which modifies the way it moves, inducing the flutter phenomenon. In the flutter condition, the vibration amplitudes of the panel become dynamically unstable and increase exponentially with time, significantly affecting the accumulated fatigue life of the existing aeronautical components [2]. This is a reason for which in the last decades, great effort has been devoted to the proposition of analytical, numerical and experimental flutter control techniques in order to prevent the flutter phenomenon, since flutter vibrations can completely destroy the structural components, leading to a catastrophe [4].

---

[*] Corresponding author. Tel.: +55 34 32 39 41 48; fax: +55 34 32 39 42 06.
E-mail address: amglima@mecanica.ufu.br (A.M.G. de Lima).

http://dx.doi.org/10.1016/j.ymssp.2016.02.025
0888-3270/

Jordan [5] was the first in the identification of the flutter in aeronautical panels by analyzing the failures occurred in the V-2 Rocket German supersonic missile used in the Second World War. More recently, many researchers have investigated the supersonic panel flutter characteristics in order to prevent it. According to Kuo [2], the variable fiber spacing in composite materials can significantly affect the supersonic flutter of rectangular composite plates by changing the sequence of flutter coalescence modes. Song and Li [6] and Almeida et al. [7] have proposed an active control strategy of the aeroelastic flutter of curved panels by using piezoceramics. Kouchakzadeh et al. [8] have evaluated the effects of the in-plane forces, fiber orientations and aerodynamic damping on the aeroelastic flutter in laminated composite plates. Zhao and Cao [9] investigated the influence of the stiffness of laminated composite panels in the supersonic flow by applying stiffeners on the surface of the plate. Sohn and Kim [10] and Prakash and Ganapathi [11] have investigated the supersonic flutter characteristics of functionally graded panels under thermal and aerodynamics loads. Scott and Weissharr [12] have used piezoceramics and shape memory alloys in order to increase the flutter velocity of plates. Zhou et al. [13] have suppressed the nonlinear panel instability under uniform thermal loading by using a modal reduction method and linear quadratic regulator linear control. Moon and Kim [14] have used active and passive suppression schemes for nonlinear flutter of composite panels by using piezoelectric elements. In the active control method, an optimal controller based on the linear optimal scheme was implemented and for the passive damping technology, the authors have used piezoelectric shunted circuits.

Hence, it can be seen that much research on the suppression of linear and nonlinear panel flutter phenomenon has been conducted by some authors by using passive, active and semi-active aeroelastic control strategies. However, surprisingly enough, applications to the case of aeroelastic analysis of viscoelastic systems are not numerous, which motivates the study reported herein. Also, despite the fact that many aeroelastic control strategies applicable to damped aeroelastic panels exist in literature [15–17], the main contribution intended for the present study is the application of passive constrained viscoelastic layers in order to suppress the aeroelastic instability of flat panels by conveniently accounting for the frequency- and temperature-dependent behavior of the viscoelastic material.

In the quest for panel flutter analyses, although the presence of the geometrical nonlinearities in the supersonic flutter phenomenon, linear theories on panel flutter provide information about airflow speed at which the panel vibrations become dynamically unstable and are capable to determine with reasonable accuracy the values of critical aerodynamic pressure and frequency [14]. In the present contribution, the Linear Piston Theory is adopted in order to model the aerodynamic loading in supersonic conditions by neglecting the effects of the aerodynamic damping, resulting in the quasi-steady supersonic aerodynamic theory known as *Ackeret's Model* [1]. Thus, the aeroviscoelastic model developed herein is valid for supersonic flow conditions, since the linear piston theory has been adopted to approximate the aerodynamic pressure acting on the three-layer sandwich plate.

At this point, it is important to emphasize that one essential limitation of the linearized analysis of the flutter problem is that it gives information only up to the point of instability (onset of instability), e.g. the critical aerodynamic pressure (or critical flutter speed), which is the case in the present work. Thus, to study the behavior of aeroviscoelastic systems in the post instability region, the inherent non-linearities of structural and aerodynamic nature must be accounted for. The present work focuses on the flutter point prediction only and the non-linearities are not considered in the model. However, it is important to emphasize that non-linearities might occur before the flutter instability, leading to a change on the aeroelastic behavior.

More recently, much effort has been devoted to the study of efficient passive control techniques to be applied to medium- to high-scale structures to mitigate undesired levels of vibration. Among these, passive control techniques based on the use of viscoelastic materials present some advantages such as inherent stability, effectiveness in broad frequency bands and moderate development and maintenance costs [18–21]. In practice, those materials can be applied either as discrete devices, such as translational mounts and rotational joints [21], or surface treatments known as Passive and Active Constraining Layer Damping (PCLD and ACLD) [18]. However, the incorporation of the viscoelastic behavior into the finite element (FE) models and the numerical approaches for resolution of the resulting equations of motion are particularly relevant aspects of the modeling procedures since for viscoelastic structures the stiffness matrices depend on frequency and temperature.

Among the standard rheological and more complex models [18] intended to represent the dynamic behavior of viscoelastic materials, the so-called *complex modulus* in combination with the *Frequency–Temperature Correspondence Principle*, leading to the concepts of shift factor and reduced frequency, has been adopted in this paper since it is adequate for eigenvalue analyses, based on which the flutter analysis of plates must be performed. However, since the stiffness matrix of the viscoelastic material is frequency- and temperature-dependent, an iterative resolution procedure is proposed herein in order to solve the resulting complex nonlinear eigenvalue problem of the viscoelastic system for a given aerodynamic pressure.

In the remainder, after the presentation of the theoretical foundations of the methodology, the description of a numerical study on the flutter analysis of a rectangular plate treated by passive constrained viscoelastic layers is addressed. The numerical study is carried-out to demonstrate that the passive viscoelastic damping treatment can effectively attenuate the flutter phenomenon. Finally, it is demonstrated that the temperature and the thicknesses of the viscoelastic and constraining layers can affect the critical dynamic pressure.