Numerical and experimental study of a pneumatic Nonlinear Energy Sink

Clément Raimond[1], Thomas Roncen[2], Thierry Jardin[3], Leonardo Sanches[1] and Guilhem Michon [1]

[1]*Department of Mechanics, ICA, CNRS, ISAE-Supaero, Toulouse, France*

[2]*Department of Mechanics, Liebherr Aerospace, Toulouse, France*

[3]*Department of Aerodynamics, Energetics and Propulsion, ISAE-Supaero, Toulouse, France*

Abstract. Aerospace systems can be subjected to severe thermal and vibration environments which may be the limiting factor in the equipment's life. A vibration protection system with adapted damping alleviates the stresses seen by the structures, enhancing their lifetime. One option is an additional device with a relatively small mass, weak dissipation, and nonlinearly coupled to a structure, also known as a nonlinear energy sink (NES). The main problem is the precise adjustment of the damping to prevent detached resonance. The present study proposes a pneumatic nonlinear energy sink which allows for tuning the damping of the NES with the aerodynamic drag. It consists of a circular metallic diaphragm which delimits two air chambers. These chambers are connected by an orifice in the diaphragm and the high-velocity air flowing through this orifice provides nonlinear damping. The theoretical design, experimental realisation and numerical simulations of this pneumatic nonlinear energy sink are developed in this work.

Introduction

Various engineering fields have progressively favoured the use of a nonlinear energy sink as a vibration absorber, mainly due to their low sensitivity to the variation of the main structure properties or the external excitation, contrary to classical linear tuned mass dampers (TMD) [1]. NES is designed to trigger an irreversible energy-pumping phenomenon called targeted energy transfer (TET) from the main structure to the absorber. This phenomenon has been widely studied theoretically and experimentally with different vibration sources. B. Cochelin et al.[2] have studied an absorber with a diaphragm for energy pumping in acoustics which damping is provided by the elastomeric material of the diaphragm. This assembly cannot be operated at high temperatures, reducing the industrial application possibilities. NES promises excellent theoretical performance but they have some shortcomings. The first flaw is the appearance of an undesirable regime called detached resonance, during which the vibration of the main structure is amplified instead of being reduced. NES parameters need to be optimised to suppress the existence of this nonlinear critical phenomenon. This phenomenon is directly linked to the damping of the NES which is very difficult to predict and customise in structures. To overcome this issue, we propose a new concept of a pneumatic nonlinear absorber with controlled damping illustrated in Figure 1. It consists of two air chambers separated by a circular diaphragm with an orifice. The diaphragm and high-velocity flow through the orifice are the key points in the design of the nonlinear elastic force and nonlinear damping, respectively. A metallic diaphragm is chosen to operate at high temperatures. The use of aerodynamic drag helps to determine the global damping of the absorber as the mechanical friction becomes negligible. Analytical treatment of the governing NES equations of motion is performed through an asymptotic approach to model the coupling between structural and fluid components analytically. This will allow the rapid development of an optimised prototype for vibration dissipation. A numerical model is used to verify that the asymptotic approach correctly describes the pumping phenomenon, and finally, experimental tests are used to validate the model and identify its limits.

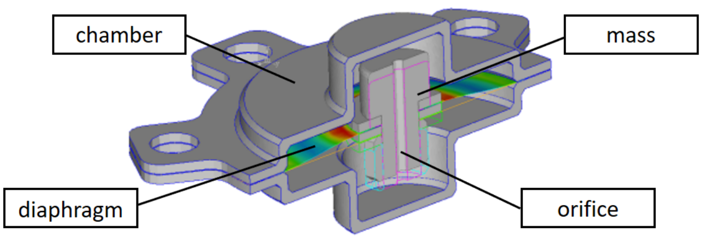

Figure 1: Sectional view of AirNES prototype

Results and discussion

As part of this study, it has been shown that this properly tuned NES achieves effective vibration absorption and outperforms classical TMD. Numerical simulations involving fluid-structure interaction agree with analytical predictions and initial experimental tests. The results will be used to theoretically design a NES which dampens the response of a resonant system while reducing the number of needed iterations in the design process.

References

[1] Gendelman, O., Manevitch, L. I., Vakakis, A. F., & M'closkey, R. (2001) Energy pumping in nonlinear mechanical oscillators: part I—dynamics of the underlying Hamiltonian systems. *J. Appl. Mech.* **68(1)**:34-41.

[2] Cochelin, B., Herzog, P., & Mattei, P. O. (2006) Experimental evidence of energy pumping in acoustics. *Comptes Rendus Mecanique* **334(11)**:639-644.