Experimental Identification of an Aircraft Piccolo Tube Exhibiting Nonsmooth Nonlinearities

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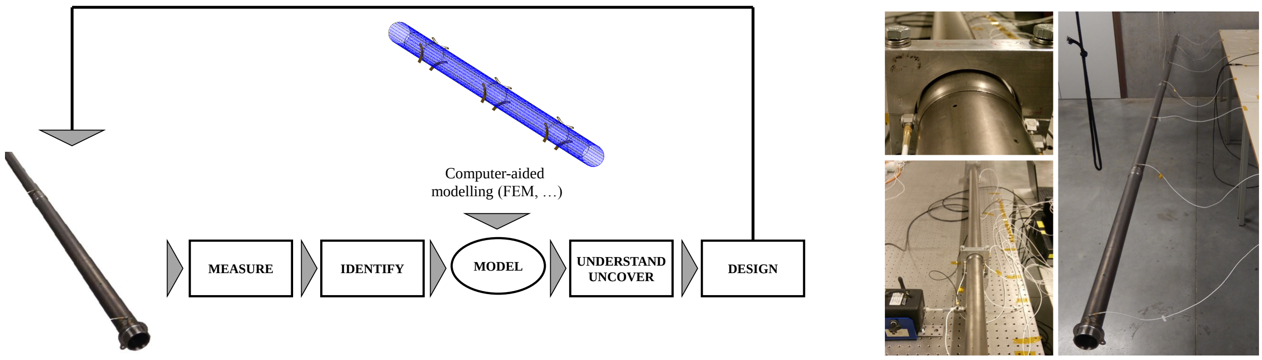
Summary. Piccolo tubes are parts of aircraft wings anti-icing system and consist of titanium pipes inserted into the internal structure of the slat. Due to thermal expansion, clearances between the tube and its support are unavoidable, and cause the overall system to exhibit highly nonlinear behaviour, resulting from impacts and friction. This paper aims the complete nonlinear vibration analysis of an aircraft Piccolo tube, from measurements and identification to a thorough understanding of the dynamics and improvements of the design.

Introduction

Piccolo tubes are parts of aircraft wings anti-icing system and consist of titanium pipes inserted into the internal structure of the slat. They distribute the hot air from the engine to the leading edge to avoid the accumulation of ice on the wings surface. During the whole duration of the flight, they are hence exposed to an important range of temperatures [1] resulting in big changes in their dimensions due to thermal expansion. Such variations lead to unavoidable gaps between the tube and its support [2]. Impacts and friction phenomena occurring in those clearances make the overall system highly nonlinear and hardly predictable.
The present paper addresses the complete nonlinear analysis of an industrial Piccolo tube mounted on its supports. The proposed methodology considers the whole design cycle of a nonlinear engineering structure. Measurements on the real structure and experimental nonlinear identification are carried out to develop a reliable nonlinear model, which is then used to thoroughly understand the complex dynamics of the mounted tube and improve its design.



(a) (b)

Figure 1: (a) Design cycle of nonlinear engineering structures, from measurements to design. (b) Experimental setup of the Piccolo tube, SONACA property, in clamped and free-free conditions.

Nonlinear Analysis Framework

As illustrated in Figure 1 (a), the proposed methodology starts from the real structure and uses experimental techniques to provide a reliable numerical model. Such a model is next exploited to fully understand the complex dynamics of the structure and reveal possible nonlinear phenomena that can jeopardise the correct functioning or even the structural integrity of the product. Based on that knowledge, new choices on the design can be made to improve the performances or the safety of the structure.

Measure

The Piccolo tube is tested both with and without the presence of its supports (Figure 1 (b)). This allows first to extract the linear modal parameters to update the linear finite element model, and then to carry out the proper nonlinear identification. A particular attention is given to the excitation signals, as both sine-sweeps [3] and random-phase multisines [4] are considered.

Identification

The nonlinear identification follows the common different steps cited in [5], from characterisation to parameter estimation. The characterisation of nonlinearities encompasses their localisation [6], their quantification [7] and the determination of their mathematical form [3]. Preliminary results of the characterisation based on sine-sweep measurements are shown in Figure 2. Impacts are clearly revealed by both the presence of a broadband frequency content around a resonance (Figure 2 (a)) and an abrupt change in the slope of the stiffness curve (Figure 2 (b)). Next, parameter estimation is carried out using a nonlinear subspace identification algorithm [8] adapted to tackle nonsmooth nonlinearities. The identified nonlinear stiffness and damping behaviours are finally added to the linear finite element model.

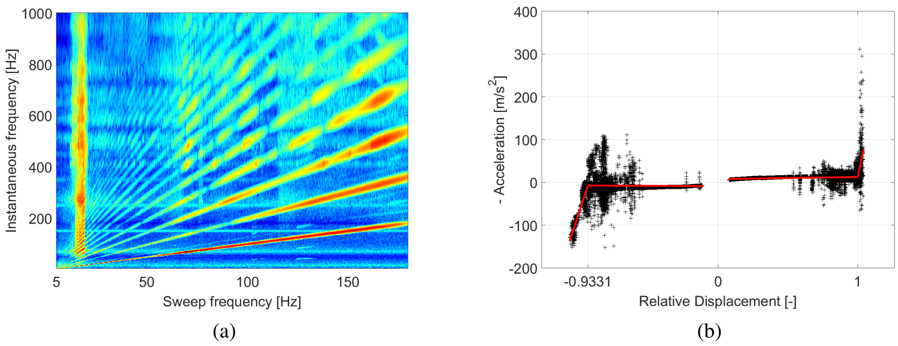


Figure 2: (a) Wavelet transform amplitude of the acceleration of the tube at the location of the support. (b) Qualitative nonlinear stiffness curve of the tube-support connection (in black), fitted with a piecewise linear model (in red).

Understand Nonlinear Behaviours and Design Improvement

Once the numerical model has been upgraded and offers a better predictive capability, it can be exploited to understand more thoroughly the impact of the nonlinearity on the tube's dynamics. It can also uncover the presence of potentially dangerous nonlinear phenomena, such as modal interactions [9] or isolated resonance curves [10]. Different options to modify the design, such as varying clearances, adding an intermediate elastomer or changing the material of the inner ring, are then considered and studied to mitigate vibration amplitudes.

Conclusions

In this paper, a complete nonlinear analysis was applied to an aircraft Piccolo tube, an industrial structure possessing strong and nonsmooth nonlinearities. Dedicated measurements and nonlinear identification were performed in order to both update and upgrade the numerical model. That enhanced model was then exploited to unveil the complex nonlinear dynamics of the tube and to investigate possible design improvements.

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References

[1] Wright, W. (2004) An Evaluation of Jet Impingement Heat Transfer Correlations for Piccolo Tube Application. *42nd AIAA Aerospace Sciences Meeting and Exhibit, Aerospace Sciences Meetings*

[2] Van Der Vorst, R., Magerman, J., Bernay, B., Vandenberk, S. et al. (2013) Vibration Qualification Test of an Aircraft Piccolo Tube Using Multiple-Input-Multiple-Output Control Technology. *SAE Technical Paper, 2013-01-2315*

[3] Dossogne, T. et al. (2015) Nonlinear Ground Vibration Identification of an F-16 Aircraft - Part II Understanding Nonlinear Behaviour in Aerospace Structures Using Sine-sweep Testing. *in Proceedings of the International Forum on Aeroelasticity and Structural Dynamics 2015*, St-Petersburg

[4] Pintelon, R. and Schoukens, J. (2001) System Identification: A Frequency Domain Approach *IEEE Press*, Piscataway, NJ

[5] Kerschen, G. , Worden, K., Vakakis, A.F. and Golinval J.C. (2006) Past, Present and Future of Nonlinear System Identification in Structural Dynamics. *Mechanical Systems and Signal Processing*, 20:505-592

[6] Detroux, T., Dossogne, T., Masset, L., Noël, J.P. and Kerschen, G. (2016) Analysis of the Nonlinear Dynamics of an F-16 Aircraft Using the NI2D Toolbox. *GDR DYNOLIN 3437, 2016*, Paris, France

[7] Vaes, M. et al. (2015) Nonlinear Ground Vibration Identification of an F-16 Aircraft - Part I Fast Nonparametric Analysis of Distortions in FRF Measurements. *in Proceedings of the International Forum on Aeroelasticity and Structural Dynamics 2015*, St-Petersburg, Russia

[8] Noël, J.P. and Kerschen, G. (2013) Frequency-domain Subspace Identification for Nonlinear Mechanical Systems. *Mechanical Systems and Signal Processing*, 40:701-717

[9] Noël, J.-P., Renson, L. and Kerschen, G. (2014) Complex Dynamics of a Nonlinear Aerospace Structure: Experimental Identification and Modal Interactions. *Journal of Sound and Vibration*, 33:2588-2607, 2014

[10] Detroux, T., Noël, J.P., Masset, L., Kerschen, G. (2016) Nonlinear Vibration Analysis of the SmallSat Spacecraft: From Identification to Design. *in 14th European Conference on Spacecraft Structures, Materials and Environmental Testing, 2016*, Toulouse, France