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MULTISCALE COMPUTATIONAL STRATEGY FOR THE DESIGN OF COMPOSITE STRUCTURES WITH MATERIAL AND GEOMETRIC UNCERTAINTIES

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ABSTRACT

The design of composite structures necessitates the use of multiscale simulations to take into account their hierarchical structure. To account for aleatory uncertainties due to the inherent scattering on material data and the geometrical tolerance, such simulations must be integrated with statistical uncertainty quantification (UQ) and propagation (UP) methods. In this work, a non-intrusive approach is proposed for multiscale UQ and UP. The different steps of the approach are illustrated by investigating the influence of structural uncertainties on the aeroelastic flutter of graphite/epoxy cantilevered plates with varying amounts of bending-torsion stiffness coupling. Monte Carlo (MC) hierarchical sensitivity analysis is performed to identify the most important parameters at the micro-mechanical, layer, and laminate levels having first order effects on aeroelastic phenomena and quantities. Attention is paid to probabilistic modelling, including dependence, of each uncertain parameter of interest, at the different scales of the material. A surrogate model, constructed on data points obtained using high fidelity aeroelastic models, is employed for achieving computational efficiency in quantifying uncertainty. The objective is also to evaluate how uncertainties influence the design analysis, from the behaviour of the laminate up to final failure.

Keywords: composite, surrogate modelling, aeroelasticity, uncertainty.

INTRODUCTION

Aeroelasticity is the discipline that deals with interactions between a given structure and fluid flow. Most of the studies in the literature are conducted with a sole focus on the deterministic analysis of aeroelastic phenomena while largely neglecting uncertainties in aerodynamic and structural parameters. However, the values of these parameters vary among different structures due to the accumulation of manufacturing tolerances or fluctuations in flight conditions. These variations are indeed uncertainties due to variations in material properties, structural dimensions, boundary conditions, and aerodynamic parameters [1].

In this work we focus on structural aleatory uncertainties (material properties, fibre orientation and geometrical variability of each ply). The employed aeroelastic models of the cantilevered plates are generated on Nastran and the doublet lattice method is employed. In-house tools and others available on the open source library OpenTurns are used for the treatment of uncertainties and their management. The prediction of the behaviour of the laminate up to final failure is performed using the ONERA Progressive Failure Model (OPFM) detailed in [2]. This model provides an accurate description of the ply behaviour by taking into account thermal residual

stresses, non-linear elasticity in the fibre direction and viscoelasticity of the matrix. Ply failure is captured through a mesoscopic stress-based failure multi-criteria which distinguishes between fibre failure (tensile and compressive failures are considered separately) and interfibre failure (corresponding to the onset of transverse cracking in the present study). The degradation of the mechanical properties of the failed plies is based on continuum damage theory. The final failure of the laminate is assumed to be due to the first ply failure in fibre mode or in transverse compression.

RESULTS AND CONCLUSIONS

The MC method is employed to choose at random (according to uniform or Gaussian distributions) values for each uncertain parameter and then to perform all the calculations associated with each set of variables, until the outputs present a sufficiently representative distribution. The uncertainty on the failure envelope of $[90^\circ/\pm 30^\circ]$ s laminate is shown in Figure 1a. A comparison with experimental data (green points) is also presented, showing both a very good agreement between the data and that the effect of uncertainty sources on the failure envelope can be significant. Sensitivity analyses on different stochastic variables are also performed for different loadings, and results are shown in Figure 1b for bi-compression loading. These results confirm the reliability of the strategy on the transfer of uncertainties from layer properties to structural performances. In this work the strategy is further validated on the analysis of aeroelastic flutter, and comparisons with data from aeroelastic wind tunnel tests and analytical solutions are also performed [3].

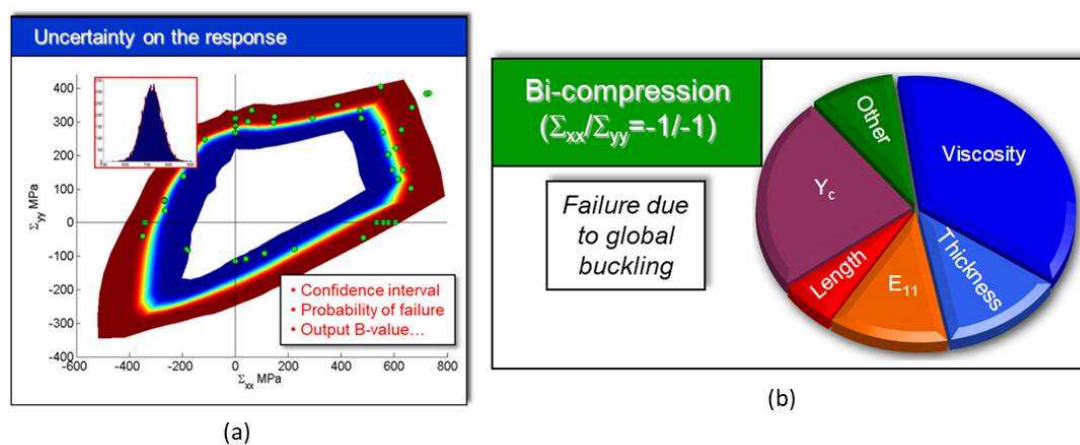


Fig. 1 – (a) Uncertainty on failure envelope of $[90^\circ/\pm 30^\circ]$ s laminate obtained using OPFM;
 (b) sensitivity analysis under bi-compression loading.

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