

Multi-scale composite reliability-based design optimization for aeroelastic applications

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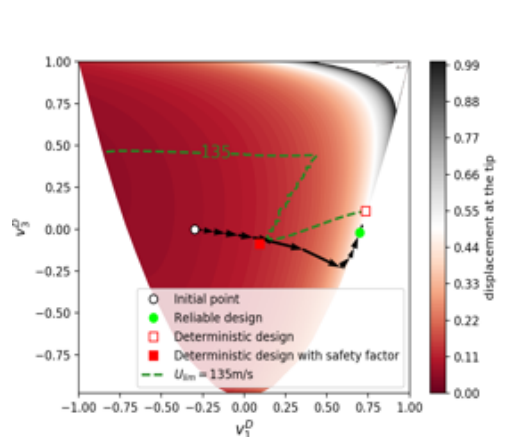
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ABSTRACT

The inherent uncertainties linked to the composite manufacturing process (e.g., material properties, thickness, ply orientations) call for a reliability-based approach to composite structural optimization [1]. Uncertainty is often introduced at lower scales of the composite material, while a more macroscopic scale is the preferred design space for optimization. This work proposes a new iterative methodology that combines a low-dimensional macroscopic design space - relying on homogenized variables - with gradient information to perform quick and accurate optimization and a high-dimensional lower-scale (ply scale) space where uncertain design variables are modeled and upscaled. An inverse problem is solved at each iteration of the optimization process to identify the low-scale material configuration that meets the homogenized parameters in terms of some statistical description. This resolution becomes viable thanks to efficient metamodel upscaling: a particular orthonormal basis is constructed with Fourier chaos expansion, which provides a very efficient closed-form expression of the macroscopic design variable statistics. Moreover, due to the multimodal nature of the aeroelastic response (i.e., the flutter velocity), a surrogate model strategy based on Gaussian process classification is implemented for the reliability analysis.

This approach is applied to a composite plate optimization with uncertain ply angles to promote the wing's flexibility while remaining reliable with respect to the flutter phenomenon. The results show a good convergence of this optimization approach with a significant improvement in reliability compared to the deterministic optimized design (cf. Fig. 1) and a significant computational gain compared to the approach of directly optimizing ply angles via an evolutionary algorithm as in [2].



Optimization path of the Reliability-Based Design Optimization, Final macroscopic design variables are compared with deterministic optimization.

References

- [1] Pettit, C. (2004). Uncertainty quantification in aeroelasticity: Recent results and research challenges. *Journal of Aircraft*, 41(5), 1217–1229.
- [2] Scarth, C. and Cooper, J. (2018). Reliability-based aeroelastic design of composite plate wings using a stability margin. *Structural and Multidisciplinary Optimization*, 57(4), 1695– 1709.