A Performance Measure Approach to composites reliability: a transmission loss application

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Although the aerospace production process is much better controlled than the process in other industries, it remains true that very small manufacturing variability exists in the geometrical parameters (flange thicknesses, hole diameters …) as well as in material properties. In the current design process, the effect of this manufacturing variability is usually compensated for by applying safety factors. This is not an ideal situation, as it may lead to slightly over-designed structures.

A much more promising approach is to include probabilistic models of design variables into the mechanical simulation process. Then, with a new methodology based on reliability analysis, engineers can obtain a better understanding of the actual effect of the manufacturing tolerances and of variability in material properties. Based on the analysis results, the robustness and reliability of the design can be assessed and improved if needed.

In this paper, the above-mentioned probabilistic approach is demonstrated on a stiffened composite panel of an aircraft and its acoustic performances in terms of transmission loss are assessed. The frequency dependent transmission loss of this composite structure is optimized with respect to two ply thicknesses and four material properties in order to obtain a high transmission loss throughout different frequencies for good acoustic insulation. The objective of this study is to maximize the minimum transmission loss throughout the entire acoustic frequency spectrum.

The structural behavior of the composite panel is calculated with the Finite Element Method, while the acoustic performance is predicted with the Boundary Element method. The combination of both modeling techniques allows accurate prediction of the panel's transmission loss. During the optimization process, the parameters are initially optimized using deterministic approaches: first a global search and then refined by a local search, without any consideration for parameter variability. The solution found by the deterministic approaches is then used as the starting point for the probabilistic approach to improve the reliability and robustness. Therefore, the Performance Measure Approach has been used. The two optimization approaches use surrogate models constructed on the results of a Design of Experiments. In this way, optimal solutions were obtained with a fraction of the otherwise required number of mechanical simulation runs.

The deterministic approaches improved the transmission loss from 8.8 dB of the reference configuration to 13.6 dB. The probabilistic approach improved the reliability from 3.27σ of the benchmark configuration to 4.0σ with a transmission loss of still 13.6 dB.

The probabilistic approach adopted for the current problem has enabled the identification of an optimal material and ply configuration that improves the reliability and robustness of the optimal solution found by a deterministic optimization. Therefore, the solution is less susceptible to variability in material properties and manufacturing tolerances and less likely to violate constraints found by the deterministic optimization, while practically maintaining the transmission loss level found by the deterministic counterpart.