SENSITIVITY ANALYSIS AND OPTIMIZATION OF SHEET STEEL THICKNESS FOR VIBROACOUSTIC BEHAVIOR OF ENCLOSURES

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ABSTRACT

In automotive applications, one of the keys to ensure weight reduction is the optimization of the sheet steel thickness. This paper presents a non-exhaustive list of sensitivity analysis methods (local, global and energy-based) allowing to determine which thicknesses could be reduced. The first results of an adaptive optimization procedure allowing reduction of the thicknesses under design constraints are also illustrated for the modal behaviour of an academic structure representing a simplified cab coupled with an acoustic cavity.
Keywords : sensitivity analysis, adaptive optimization procedure, sheet steel thickness.

1 INTRODUCTION

The design of novel cars and cabs for urban and peri-urban areas should take into account environmental constraints. Indeed one of the keys in the project is to reduce the weight of the cabs in order to reduce the energy consumption. Thus it is important to locate the different zones where the thickness of the sheet steel thickness could be reduced without deteriorating the dynamic and acoustic behaviours.

There are many sensitivity analysis methods allowing to know which sheet steel thicknesses could be reduced. Some of them are presented in the first part of this paper, divided into three classes : local, global and energy based. Each of them has different advantages and drawbacks. A benchmarking has been done in order to choose the one that can be used in the context of the optimization procedure of interest.

In a first step, an optimization procedure has been developed for modal behaviour. The procedure is adaptive and can iteratively reduce or increase the sheet steel thicknesses according to the constraints design in order to obtain a robust final design for the cab.

2 SENSITIVITY ANALYSIS METHODS

In order to describe the different sensitivity analysis methods, the test-case used is a finite element model of the aircraft used in the GARTEUR project (Group for Aeronautical Research and Technology in Europe) [1]. The sensitivities of the Young's modulus and mass density of each material are evaluated with respect to the eigenfrequencies and the value of the paired MAC (Modal Assurance Criterion) for the first five modes.

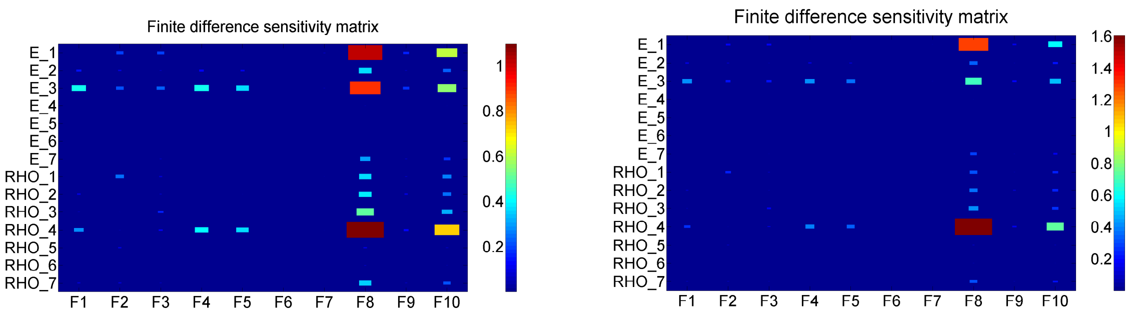
2.1 Finite difference sensitivity analysis

The most commonly employed technique to evaluate the sensitivity of parameters is the finite difference approach, which consists in evaluating the gradient of the responses of the system with respect to each parameter individually. The sensitivity indicator is given by [2]:

$$\phi_i = \frac{\frac{Y(X_1,\ldots,X_i+\Delta X_i,\ldots,X_n)-Y(X_1,\ldots,X_i,\ldots,X_n)}{Y(X_1,\ldots,X_i,\ldots,X_n)}}{\frac{\Delta X_i}{X_i}} \quad (1)$$

where Y is the response of the system, X_i the parameter i and ΔX_i the small variation of X_i.

This method is relative inexpensive but results can change according to the value of ΔX_i and it strongly depends on the nominal model which may be not validated. Figure 1 shows the results of the method for two different values for ΔX_i.



(a) $\Delta X_i = 0.1\%$

(b) $\Delta X_i = 10\%$

Figure 1. Results of the finite difference method with different values for ΔX_i

2.2 Global sensitivity analysis methods

Global sensitivity analysis methods take into account the probability density function of the parameters and explore all the design space. For example, the method of Morris [3] allows the computation of the sensitivity of parameters by calculating several times the elementary effect of each parameter. The sensitivity indicators are the mean (μ) and the standard deviation (σ) of the elementary effect. The mean gives information about the overall influence and the standard deviation indicates if the parameters have a coupling effect with other(s) parameter(s) or a non-linear effect. The results of the method are observed for each response in the (μ,σ) plane.

Other global sensitivity analysis methods have been tested on the structure such as the correlation coefficient allowing to know if it exists a linear relation between a parameter and a response, a principal component analysis which transforms the physical variables space into a purely mathematical space in which a singular value decomposition is performed. In order to compare different kinds of sensitivity analysis methods, we also performed a FAST [4] analysis which is based on the variance analysis. This method is efficient but time-consuming.

2.3 Energy-based methods

Two different energy indicators have been applied on the model to evaluate the sensitivity of the parameters. These indicators are interesting because one can calculate at low cost some spatial information related to sensitivities of responses due to changes in the structure. The first indicator is the strain energy which could be evaluated after a modal analysis as presented in [5], while the other one is an indicator developed in [6], based on a non-parametric sensitivity analysis [7] in which the mass and stiffness matrices are disturbed by a random matrix whose mean value is the identity.

3 OPTIMIZATION PROCEDURE

An optimization procedure is developed based on the strain energy normalized by the volume of the zone. The following indicator is used to rank the sheet metal zones:

$$I = \frac{1}{2} y_k^T K^i y_k \frac{V_i}{V_{tot}} \tag{2}$$

where y_k is the k^{th} eigenvector, K^i and V_i are the stiffness matrix and the volume of elements with the i^{th} thickness and V_{tot} the total volume of the structure. The flowchart of the optimization procedure is given in Figure 2 and can be summarized as follows:

1. Prepare the model features, the zones with imposed constant thickness, the parameters of the procedure such as the number of modes, make a first modal analysis to set the two different thresholds allowing to know which thicknesses could be modified.
2. Evaluate the indicator for each set.
3. Sets are selected for which the thickness has to be reduced.
4. Sets are selected for which the thickness has been too much reduced, so thickness is increased.
5. The model is updated according to step 3 and 4.
6. A modal analysis is performed with the new thicknesses.

7. The convergence is checked. If achieved the procedure will stop otherwise go to step 2.

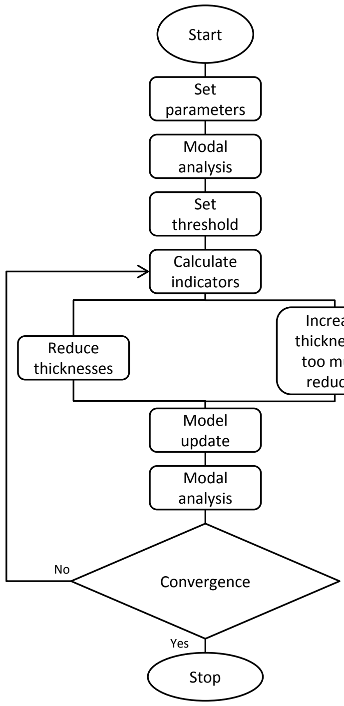


Figure 2. Flowchart of the adaptive optimization procedure.

Preliminary results with a simplified model of the cab show a weight reduction of 3% but with design constraints and threshold that have been set to an arbitrary value in order to test the procedure.

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