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Correlation between Numerical and Experimental Analysis Using Model Updating Techniques

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Abstract. With the increasing complexity of the products, engineers face a higher level of uncertainty in both simulation and test. Correlation between numerical and experimental analysis using model updating techniques helps engineers to asses uncertainty. Present research efforts focus to combine finite element analysis and testing in one common framework. Experimental and operational modal analysis and simulation make benefit from common databases. Some applications presented emphasize the advantages of these techniques.

1. Introduction

The development cycle of a new product involves a mixture between experimental and simulation techniques. In order to meet the specifications, engineers with different backgrounds must work together and share common data. Model updating techniques provide a common framework for testing and simulation with benefits for both fields.

Model updating techniques have a whole range of industrial applications including multi-physics simulations and non-linear dynamics. The paper presents applications of model updating techniques and explores relations between experimental analysis and finite element modeling.

2. Pre-test analysis

Some finite element models are already available in early stages of product development process. Those models are the results of best design scenarios and/or optimizations problems. The engineers can make use of this baseline finite element models in pre-test analysis.

The purpose of pre-test analysis is to plan and optimize experimental tests on prototypes. Experimental and Operational Modal Analysis (EMA/OMA) are the most common methods used to evaluate the response of mechanical structures. Consequently, using the baseline finite element models, the engineers can predict the mode shapes in the frequency band of interest and the results can be post processed for [1],[2]:

- Target mode selection
- Selection of candidate sensor locations
- Optimal locations and directions for sensors, actuators and suspension using sensor placement metrics and sensor elimination methods
- Pretest sensitivity analysis (influence of instrumentation mass, suspension and/or clamping stiffness)
- Stress analysis to avoid overloading
- Computing normal directions at test locations
- Derive test model from FEM and export to test software

Figure 1 presents an example of nodal modal displacement plot (NMD) – average of modal displacements for the first five modes [3]. The plot can be easily interpreted in order to choose the best locations and directions for sensor placement (automatic or manual). Given the maximum number of sensors and a selection criterion, the engineer can select the best testing configuration.

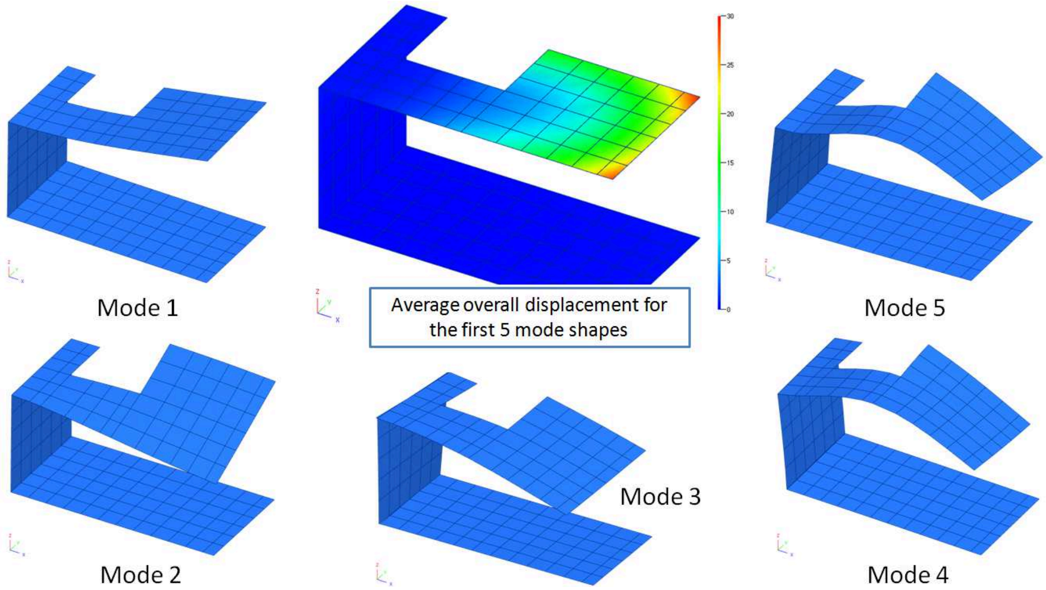

Fig. 1 Pre-test analysis using a baseline finite element model. Average overall displacement plot for the first five modes shows the best locations for sensor placement.

Figure 2 presents the selection of four locations for tri-axial sensor placement. In this example MAC (modal assurance criterion) matrix serves as selection criterion (minimum off-diagonal values). Off-diagonal values of MAC matrix show that spatial aliasing is acceptable for this test configuration. Automatic sensor selection is possible for quick and powerful test planning [3].

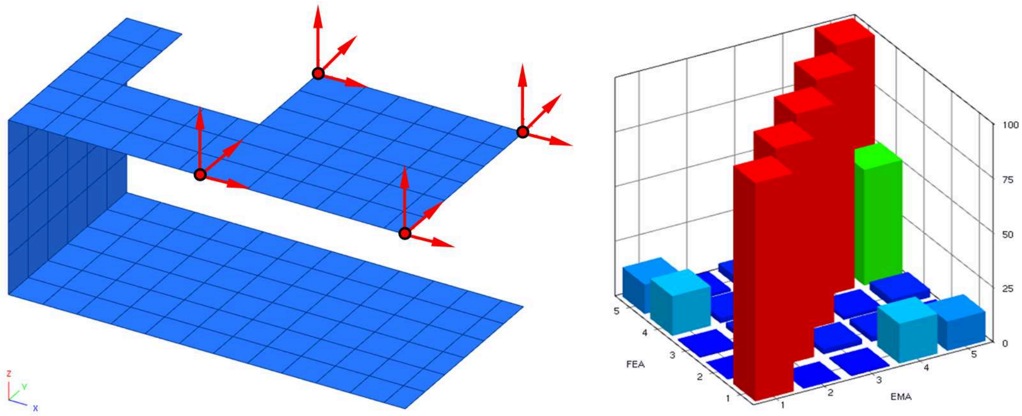

Fig. 2 Selection of four locations (left) for tri-axial sensor placement based on NMD plot. MAC-matrix (right) serves as selection criterion.

3. Experimental and Operational Modal Analysis

Testing provides a “reality check” of the design. The assumptions on which the finite element models are built can be validated based on experimental data. The most common test performed on complex products are experimental and modal analysis (EMA/ OMA).

The modal parameters estimated from measurements are natural frequencies, mode shapes and damping ratio. In EMA the structure is excited with a known force and the response in some points is measured. The output spectrum is divided with the input spectrum to obtain the Frequency Response Functions (FRF).

OMA is also called output-only modal analysis and uses a stochastic framework where the input now is assumed to be a stochastic process [4],[5]. The input excitation is not known and/or controlled and it must be broad-banded in the frequency range of the modes of interest. OMA separates noise and input and returns the same modal information as EMA [6].

Both EMA and OMA are industry standard methods. EMA works best if the structure can be mounted in a test rig. The FRF are in principle very clean since the known input is extracted from the measured output. OMA works best for large structures or any structure subjected to external uncontrollable operational forces. Some of the modes appearing in the measured response might not originate from the structure itself but from the input.

Natural frequencies, mode shapes, FRFs, damping ratios form the basis for model updating techniques. The discrepancies between finite element models and EMA/ OMA responses are quantified and correlation coefficients define the level of correlation, identifying zones with maximal discrepancy.

4. Finite Element Model Updating

The objective of model updating is to quantify the differences between finite element analysis results and corresponding reference data, and then to modify the numerical values of the input parameters in the model, or the model itself, to obtain a valid model [1]. The reference data are in general modal parameters obtained by EMA/ OMA. Updating parameters may be global (material properties) or local (thickness, beam cross-section, joint stiffness).

The first step is to create relation tables between analytical and experimental responses: relations between points and nodes (spatial correlation), relations between numerical and experimental degrees of freedom, pairing between experimental and analytical mode shapes (shape correlation). Then, the discrepancies between FEM and EMA responses are quantified and a sensitivity analysis is performed. A new set of values for parameters is estimated and the database is updated. Figure 3 presents the automated algorithm used for model updating. The automation is in the loop and the convergence is achieved typically in 5 to 10 iterations [3].

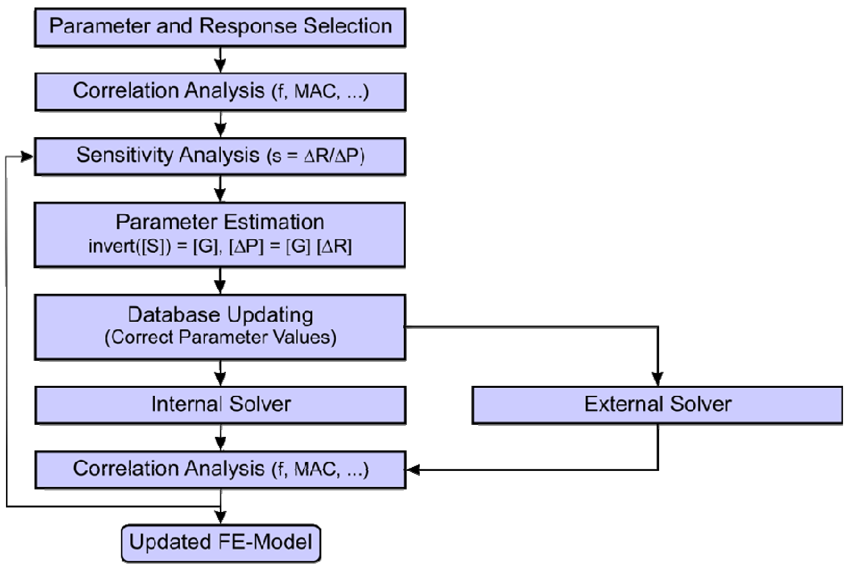

Fig. 3 The automated algorithm for finite element model updating.

The proper choice in the selection of parameters and responses and in the interpretation of the results is the key for success in model updating techniques. Although there are many parameters that can be changed in model updating, the changes in the model should remain within the range of expected variance of input parameters. It should be noted that it is the engineer who decide which are the meaningful changes in order to increase confidence in the finite element model.

Figure 4 presents an example of model updating for a stick model of an aircraft. This type of finite element model is commonly used in flutter analysis. High uncertainty is associated with the equivalent beam properties and equivalent joint stiffness. Model updating and validation play a crucial role in order to predict reliable flutter speeds in subsequent fluid-structure interaction simulations [7].

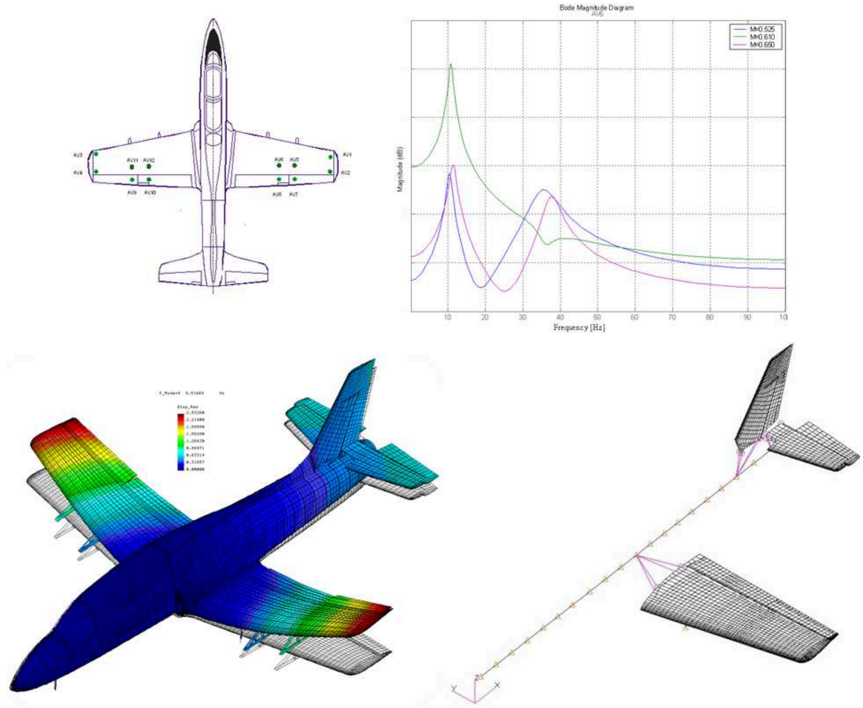

Fig. 4 Identification of beam properties and joint stiffness for an aircraft stick model. Bending and torsion modes of the wing are correlated with test data [7]

5. Conclusions

Engineers share a common database during the design cycle of the product, thus finite element analysis and experimental analysis must be connected together within a common framework.

Using model-updating techniques, engineers are able to use FEA results to optimize experimental setups. The test results are used as reference data to validate finite element models, reducing uncertainties in input parameters.

In general, model updating techniques can be applied in validation of modeling assumptions and simplifications, assessment of variability on input data, local mesh refinement, creation of reduced component models validated in a given frequency domain.

Other applications include identification of material properties or equivalent geometrical properties, identification of beam properties, characterization of joints, identification of damping, force identification, structural health monitoring (qualitative and quantitative identification of damage using a reference FE model and test data on damaged structure).

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Experimental Stress Analysis and Materials 14
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