MODEL UPDATE OF LARGE COMPLEX SPACECRAFT WITH MODAL DATA

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Summary In structural dynamics, finite element model (FEM), which is a computational representation of structure, plays a key role in analysis of large complex spacecraft. Finite element model may be different from the real structure because of simplifying, uncertainty of boundary conditions and material properties. In order to accurately predict structure response, the FE model needs to be updated. A sensitivity-based model updating approach is proposed in this paper. The Least Squares method is employed for parameter estimation. A subscale model of satellite was chosen in numerical study as example. Results show significant improvements in the correlation of analytically and experimentally obtained modal parameters after updating.

INTRODUCTION

In order to know the dynamic characteristics of spacecraft structures, accurate finite element models are needed. With the rapid development of aerospace technology, higher demands on the reliability and accuracy of their FE models are imposed. Ideally, the modes analysis and modal testing should yield the same results. In practice, however, they rarely do especially in the case of complex structure. It’s because that joins, boundary conditions and nonlinear effect are modeled difficultly [1]. So it is necessary to improve the accuracy of FE model, and model updating method was developed.

ANALYSIS APPROACH

Sensitivity Analysis

Sensitivity coefficients are defined as the rate of change of a particular response quantity ***R*** with respect to a change in an analysis model property ***P*,** also referred to as parameter. In matrix form:

$$\boldsymbol{S} = \frac{\partial \boldsymbol{R}}{\partial \boldsymbol{P}}. \tag{1}$$

Sensitivity analysis can also be used to select model parameters. In fact, model updating cannot proceed if all parameters is selected for update. To reduce the number of parameters, a linear sensitivity analysis is conducted and only those parameters showing the greatest impact on the resulting response change are retained.

The functional relationship between the modal characteristics and the structural parameters can be expressed in terms of a Taylor series expansion limited to the linear term. This relationship can be written as [2]:

$$\boldsymbol{R}_e = \boldsymbol{R}_a + \boldsymbol{S}\left(\boldsymbol{P}_u - \boldsymbol{P}_0\right). \tag{2}$$

Where:

$\boldsymbol{R}_e$, Vector containing the reference system responses (experimental data).

$\boldsymbol{R}_a$, Vector containing the predicted system responses for a given state $\boldsymbol{P}_0$ of the parameter values.

$\boldsymbol{P}_u$, Vector containing the updated parameter values.

Parameter Estimation

The Least Squares method is employed for parameter estimation. If the number of parameters is lower than the number of equations, parameter update was calculated as follow:

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$$P_u = P_0 + \left[S^T S \right]^{-1} S^T \left(R_e - R_a \right). \tag{3}$$

If the number of parameters exceeds the number of equations, then parameter update was calculated as follow:

$$P_u = P_0 + S^T \left[S S^T \right]^{-1} \left(R_e - R_a \right). \tag{4}$$

NUMERICAL APPLICATION

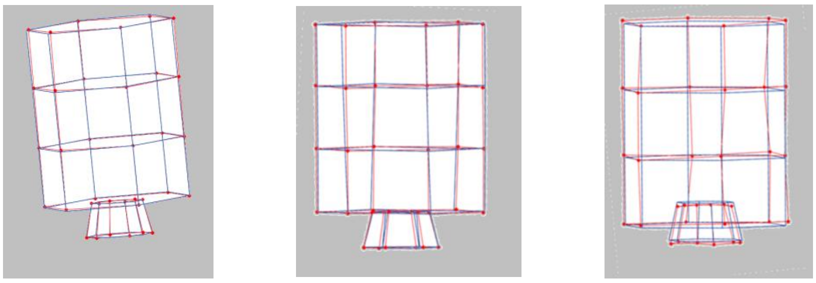
A finite element model is created by MSC/PATRAN. The FEM has 6341 grid points and 6702 elements. The model was tested while resting on a metal ingot. Because of the unconventional boundary conditions, CBUSH spring elements was used to model the boundary conditions. Comparison of analysis and testing was shown in Tab.1. Obviously, the error is too big to be used in engineering, and model must to be updated. Using engineering judgment, and sensitivity values, five parameter variables was retained for model update. After update, the accuracy of FE model was improved, as shown in Tab.2 and Fig. 1.

Table 1 Comparison before update

Mode No.	FEM/Hz	Test/Hz	Error	Mode Description
1	64.403	14.398	347.3%	1^{st} bending
2	174.75	103.61	68.65%	1^{st} Torsion
3	342.78	117.16	192.58%	1^{st} Vertical

Table 2 Comparison after update

Mode No.	FEM/Hz	Test/Hz	Error	MAC	Mode Description
1	14.7	14.398	2.1%	98.8%	1^{st} bending
2	99.86	103.61	-3.62%	98.2%	1^{st} torsion
3	124.8	117.16	6.52%	95.8%	1^{st} vertical



(1) 1st bending (2) 1^{st} torsion (3) 1^{st} vertical

Fig.1 Comparison of Modal shapes after update (red for test and blue for FEM)

CONCLUSIONS

The focus of this paper was to introduce the sensitivity-based model updating method to help improve accuracy of FE model. Errors, over 300% initially, were reduced to under 7%, worst case. The sensitivity-based model updating method has proven to be an effective method.

References

[1] Mentzer, J. R.: Application of Artificial Boundary Conditions in Sensitivity-Based Updating of Finite Element Models. ADA471415/XAB, 2007

[2] Aimin Yuan.: Studies on Several Key Problems of Finite Element Modal Updating Based on the Sensitivity Analysis. *PhD Thesis*, SEU, Nanjing,2006.