ICSV13 - Vienna
The Thirteenth International Congress on Sound and Vibration
Vienna, Austria, July 2-6, 2006

PREPARATION FOR THE VALIDATION OF A SIMPLE ELEVATOR MODEL

I. Isasa[*1], S. Cogan[2], J. M. Pagalday[1], X. Sagartzazu[1] and J.M. Abete[3]

[1]Ikerlan S. Coop., Research centre
J.M. Arizmendiarreta 2, 20500 Arrasate-Mondragón, Gipuzkoa, Spain
[2]University of Franche-Comté, FEMTO-ST Institute
24, rue de l'Epitaphe, 25000 Besançon, France
[3]University of Mondragón
Loramendi 4, 20500 Arrasate-Mondragón, Gipuzkoa, Spain
iisasa@ikerlan.es

Abstract

Despite the availability of complex and highly detailed finite element models to guide the analyst in the design and diagnosis of their real physical counterparts, establishing the credibility of model-based decisions still remains a delicate process. This is essentially due to the presence of a wide variety of uncertainties, both aleatory and epistemic, which have a direct impact on the fidelity of the model predictions and thus the models usability. The objective of a model validation methodology is to rationalize the process of establishing model credibility for a well-defined application by attempting to insure that: (1) the model calculations are performed correctly, (2) the essential physical effects have been taken into account, and (3) the sources and effects of variability have been evaluated. The objective of this article is to illustrate several essential steps of this process on a simple elevator model in preparation for a full-scale elaboration in the near future.

INTRODUCTION

The vibration and sound that a rider perceives during elevator travel is directly related to the perception of the quality of the installation. Comfort is a broad term and sometimes difficult to measure due to its degree of subjectivity, but in this paper it will be understood to mean the level of vibration that the passenger is perceiving during elevator travel, usually in the frequency range of 0-25Hz [6]. With the aim of obtaining a better knowledge of the elevator dynamics, different model approaches have been carried out in the past years. Some of them use lumped parameters [5][7][8], while others take into account the moving continua [2],[9] .

This paper focuses on the preparation of a simple lumped elevator model for model validation by evaluating the importance of including a detailed model of the elevator guide stiffness as well as studying the impact of the number of sensor degrees of freedom (dof) on several essential steps of the model update.

SIMPLE ELEVATOR MODEL

The modeling presented in this paper is focused on the mechanical elements of the elevator, modeling them as translational or rotational masses and springs. As can be seen in the Figure 1 the model consist of three pulleys (the pulley of the cabin, the pulley of the counterweight and the drive pulley), cables, arrivals of the cables, the cabin and the counterweight. The system has 10 degrees of freedom: 7 translational (X_1, X_2, X_3, X_4, X_5, X_6, X_7) and 3 rotationals (X_8, X_9, X_{10}).

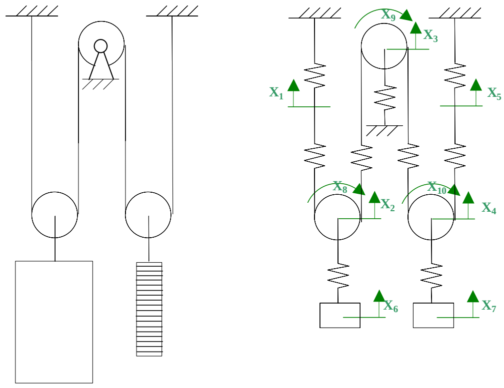
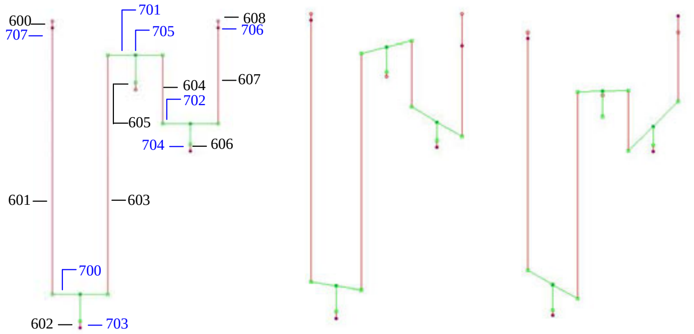


Figure 1 – Schema of elevator model.

An elevator is complicated to simulate and for this reason some assumptions were made. Firstly the horizontal vibration of the system has been neglected, as well as the damping of the system. Furthermore, the cables are modeled with springs and the variation of the behavior of the cables with time is not taken into account. Finally, the study of this system will be carried out for two eigenfrequencies in the frequency range between 1-25 Hz (Mode 2: 5,09Hz and Mode 3: 23,27Hz, Mode 1 is not taken into account because it is a rigid body mode).

The MSC/NASTRAN model has been made as shown below:



Element Number	Value
600	6e+8 N/m
601	6.22e+5 N/m
602	1.60e+7 N/m
603	6.22e+5 N/m
604	3.11e+6 N/m
605	112e+5 N/m
606	1e+8 N/m
607	3.11e+6 N/m
608	386400 N/m
700	49 kg
701	529.5 kg
702	2 kg
703	900 kg
704	1400 kg
705	23.5 kg
706	0.01 kg
707	0.01 kg

Figure 2 – NASTRAN model (Left). Mode 2 at 5.09 Hz (Center). Mode 3 at 23.27Hz (Right).

In order to simulate the experimental data, a second model is created by changing the values of two parameters corresponding to the stiffness of the cables of the counterweight (element 605) and the stiffness of the structure where the drive motor is located (element 608). These two models will be used to illustrate the various essential phases of the model validation process and in particular, to study the impact of the number of observed dofs. Toward this end, three different configurations will be analyzed. Configuration 1 is the configuration where only 2 dofs (of the 10 dof) are measured, configuration 2 is the configuration where 4 dofs are measured, whereas configuration 3 is the configuration where all 10 dof are assumed to be measured.

MODEL VALIDATION

Model validation is the field of inquiry concerned with establishing the level of credibility one can reasonably accord to numerically simulated results and how one might go about improving an unreliable model. In the context of this article, a simplified representation of the model validation process is shown in Figure 3.

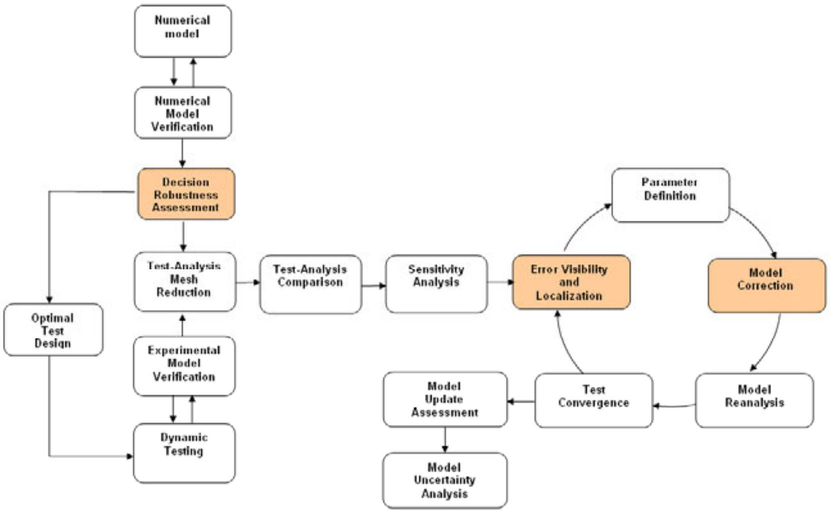


Figure 3 – Model Validation Schema.

Due to space limitations, only the phases of Decision Robustness Assessment, Model Error Visibility and Localization, and Model Correction will be discussed in this article.

Decision Robustness Assessment

An early phase in establishing the credibility of a model is based on evaluating the impact of uncertainties in the model and its environment on some measure of system performance. Three broad scenarios can be imagined:

1. The design decisions are relatively insensitive to system uncertainties, hence a costly model validation may not be a necessary.
2. The design decisions are highly sensitive to system uncertainties, hence a hefty security margin may be the most reasonable solution since high-fidelity model would be very costly to obtain.
3. The design decisions are relatively sensitive to system uncertainties, hence a model validation for improved fidelity may be economically feasible.

Info-gap Uncertainty Analysis

An info-gap uncertainty analysis may be used to study the impact of uncertainties on system performance [1]. The three components of an info-gap analysis are: Decision model, Info-Gap uncertainty model and System Performance criterion. An info-gap robustness analysis answers the question: What is the largest amount of uncertainty, α^* that the system can sustain without sacrificing a given level of performance (R_C)?

$$\alpha^* = \arg\max_{\alpha \geq 0} \max_{u \in \mathbf{U}(\tilde{u}, \alpha)} \left\{ R(q,u): \; R(q,u) \leq R_C \right\} \tag{1}$$

where u is a vector of uncertain quantities, q a vector of decision variables, R_C the critical level of performance and α the scalar that defines the horizon of uncertainty.

To illustrate an info-gap robustness analysis, we will ask the following question: Is it important to have a high fidelity model of the elevator guides in order to accurately predict the response level in the cabin? One approach to answering this question is to study the impact of uncertainty in the elevator guide model on the performance criteria of importance (eigenfrequencies, response levels, etc). High robustness to uncertainty means that a high fidelity model may not be required whereas low robustness may indicate the contrary.

To perform this analysis, a stiffness is added between the cabin and the ground to represent the elevator guides. The initial value of this stiffness is set to *1 N/m*, which is negligible. The value of α here is defined by the ratio between the current stiffness and some maximum stiffness value fixed at *1e+7 N/m*. In the present case, the solution of the robustness problem is trivial since we know that the eigenfrequencies will increase monotonically with the guide stiffness as shown in Figure 4.

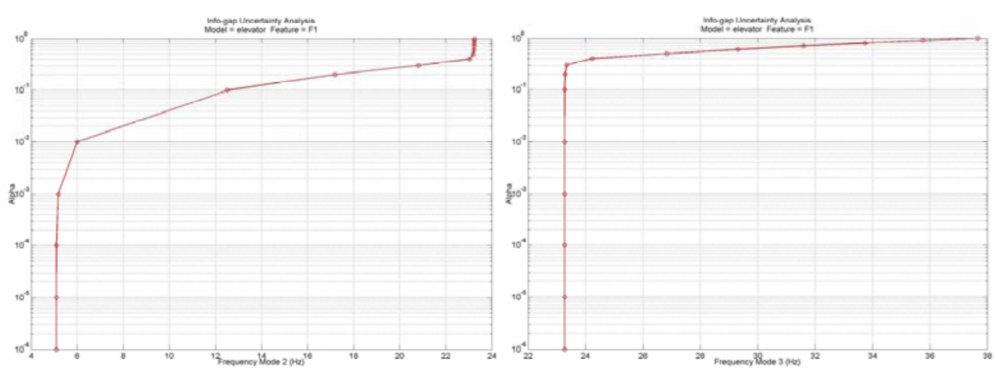


Figure 4 – Info-Gap uncertainty analysis for the two modes.

An examination of these two robustness curves leads to the following conclusions:

- Both curves show zones of both high and low robustness depending on the level of uncertainty.
- The frequency of mode 2 is insensitive to uncertainty in guide stiffness up to values of *1e+4 N/m* after which it becomes progressively more sensitive. Then at high stiffness values, it becomes relatively insensitive again.
- The frequency of mode 3 is completely insensitive to uncertainty in guide stiffness up to values of *2e+6 N/m* after which it becomes very sensitive.

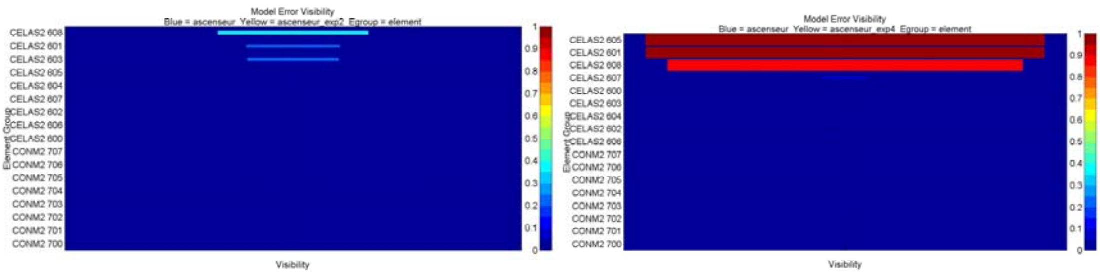
Subdomain Visibility

We propose to use a model error localization indicator based on the minimization of the Constitutive Equation Error [3]. The confidence that can be accorded to this indicator depends on the number and location of the sensor dofs as well as the subdomains to be localized. A subdomain *visibility* indicator has been developed to be used in conjunction with the model error indicator as an aid in interpreting the localization results [4].

$$V_i = \max_q \left(\frac{q^T S^T K_i S q}{q^T S^T K S q} \right) \qquad (2)$$

where, $K_i \in \Re^{N,N}$ sparse stiffness matrix of the subdomain, $K \in \Re^{N,N}$ global stiffness matrix, $F \in \Re^{N,N}$ matrix of unit forces at the sensor locations, $S \in \Re^{N,c}$ static displacement matrix $S = K^{-1}F$ and $q \in \Re^{c,1}$ vector of generalized coordinates.

The visibility (V_i) of a subdomain lies on the interval $0 \le V_i \le 1$. Low visibility values indicate that the localization results for the corresponding subdomains should be interpreted with caution. The visibility indicator is a necessary condition for the valid localization results but not a sufficient one. This means that an erroneous subdomain with high visibility may still not be localized as being in error simply because it is not sufficiently sensitized in the observed behaviors. The subdomain visibility indicator for the three test configurations of the elevator is shown in Figure 5:



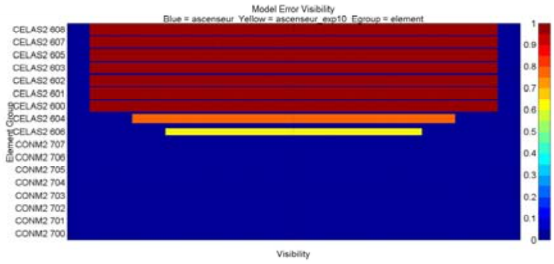


Figure 5 –Visibility Indicator for three test configurations.

Some remarks:

- The visibility of the stiffness elements increases with the number of sensor dofs.
- While the first test configuration with only 2 sensors gives globally unsatisfactory results, the second configuration with 4 sensors provides visibility for both erroneous stiffness variables (elements 605 and 608).

Model Error Localisation

Localization methods are diagnostic tools for helping the analyst decide which subdomains of the model are incorrectly characterized. One such indicator, is based on the minimization of the constitutive equation error [3]:

$$\varepsilon_i = \frac{r_\nu^T (K_i + \tilde{\omega}_\nu^2 M_i) r_\nu}{\tilde{\phi}_\nu^T (K_i + \tilde{\omega}_\nu^2 M_i) \tilde{\phi}_\nu} \tag{3}$$

where $r_\nu \in \Re^{N,1}$ is the residual eigenvector, $\tilde{\phi}_\nu \in \Re^{c,1}$ is the experimental eigenvector, $\tilde{\omega}_\nu$ the experimental angular eigenfrequency and K_i, M_i are the stiffness and mass matrices of the i^{th} subdomain. The subdomain error localization indicator for the three test configurations of the elevator is shown in Figure 6:

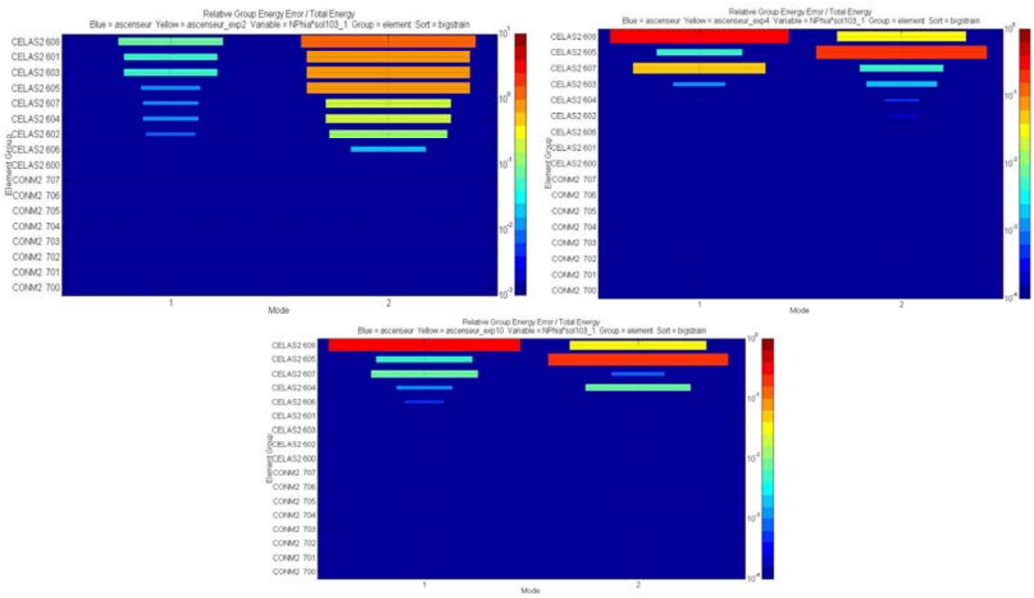


Figure 6 –Error Localization Indicator for three test configurations.

Some remarks:

- Given the visibility results for configuration 1, only the first design variable (CELAS 608) should be retained.
- The visibility results for configurations 2 and 3 are acceptable for the erroneous variables CELAS 608 and 605 which have been correctly localized.
- The results for configuration 2 also tend to localize the variable CELAS 607 (note the logarithmic scale) which is not visible and should thus not be taken into account.
- The variable CELAS 607 is visible in configuration 3 but the localization error is now 100 times smaller than for the variables CELAS 608 and 605, hence it should not be taken into account.

Model Correction

Model correction is concerned with interpreting the results of the error localization process and implementing modifications, either by remeshing or by parameter corrections, in the numerical model in order to improve the overall fidelity. Here, a computational model update is performed based on the minimization of the constitutive equation errors for the three configurations based on the model error localization results.

Configuration 1

In configuration 1, only the design variable CELAS 608 is active. The results of this update can be summarized as:

- The global constitutive equation error increases by 1.2 %. This error should normally decrease following a successful model update.
- The value of the design variable increases by 12% instead of decreasing by 70%.
- Although mode matching is not required for this procedure, it is necessary if we want to follow the output errors (eg eigenfrequency and MAC errors). In this case, given the poor distinguishability of the eigenmodes with only 2 sensor dofs, the automatic mode pairing procedure failed.

Configuration 2 and Configuration 3

In configuration 2 (the results of configuration 3 are basically identical to those in configuration 2), the design variables CELAS 608 and 605 are active. The results of this update can be summarized as:

- The global constitutive equation error for both eigensolutions is divided by approximately 10^4 which indicates a dramatic improvement over the nominal model error.
- The design variables have converged to their near exact values for the simulated experimental model (coefficients of 0.299 instead of 0.3 for CELAS 608 and 0.505 instead of 0.5 for CELAS 605).
- The automatic mode matching procedure functioned correctly here and the eigenfrequency errors went from -37.9% to 0.4% for mode 1 and -41.2% to 0.5% for mode 2.

Some remarks:

- The number of sensor dofs are seen to be critical to a successful model update. If the true erroneous design variables are both visible and correctly localized, then a model update can be performed under acceptable conditions.
- In this academic example, no significant improvement in updating results is obtained with the additional cost of 6 sensor dofs in configuration 3. However, the impact of additional sensors may be more dramatic in the presence of measurement noise.

CONCLUSIONS

This paper has illustrated some key phases of the model validation process on a simple simulated elevator example. The importance of assessing the impact of uncertainty on model-based decisions cannot be overemphasized and an example of defining the model structure has been presented. The importance of careful test design has been highlighted by studying the impact of the number of sensor dofs on the visibility and localization of modeling errors as well as their correction. These principles will be studied further in the near future using experimental elevator data. In particular, the Decision Robustness Assessment will be used to study the impact of a non-linear guide stiffness and to evaluate the level of detail required in the modeling of this interface.

REFERENCES

[1] Ben-Haim Y., *Information-gap Decision Theory: Decisions Under Severe Uncertainty. (*Academic Press, San Diego, 2001).

[2] Kaczmarczyk S. and Ostachowicz W., “Non stationary responses of cables with slowly varying length”, International Journal of Acoustics and Vibration, **5**, 117-126 (2000).

[3] Ladeveze P., Nedjar D. and Reynier M., “Updating of finite element models using vibration tests’, AIAA Journal, **32(7)**, 1485-1491 (1994).

[4] Michot S. and Cogan S., “Visibility and localisation of modelling errors using a constitutive equation error”, ISMA, Leuven, 20-22 (2004).

[5] Nai K., Forsythe W. and Goodall R.M., “Modelling and simulation of a lift system”, IMA Conference on Control (1992).

[6] Pagalday J.M., Sagartzazu X., Mardaras A., Calzada M. and Madoz M.A., “Implementation of a theoretical-experimental model for improving the comfort in lift installations”, ISMA, Leuven, 3611-3624 (2004).

[7] Roberts R., “Control of high-rise/high-speed elevators”, Proceedings of the American Control Conference, Philadelphia, Pennsylvania, 3440-3444 (1998).

[8] Zhou Y.Q., “Models for an elevator hoistway vertical dynamic system”, Fifth International Congress on Sound and Vibration, December 15-18, Adelaide, South Australia (1997).

[9] Zhu W.D. and Chen Y., “Forced response of translating media with variable length and tension: application to high-speed elevators”, Institute of Mechanical Engineers Journal of Multibody Dynamics, **219**, 35-53 (2005).