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Developing Information-gap Models of Uncertainty for Test-analysis Correlation

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ABSTRACT

Relying on numerical simulations, as opposed to field measurements, to analyze the structural response of complex systems requires that the predictive accuracy of the models be assessed. This activity is generally known as "model validation".[2] Model validation requires the comparison of model predictions with test measurements at several points of the design / operational space. For example, numerical models of flutter must be validated for various combinations of fluid velocity and wing angle-of-attack. Because validation experiments become expensive when the system investigated is complex, only a few data sets are generally available. This lack of adequate representation of the design / operational space makes it questionable whether statistical models of predictive accuracy can be developed.

In this work, we focus on one aspect of model validation that consists in assessing the robustness of a decision to uncertainty. In this context, "decision" refers to assessing the accuracy of predictions and verifying that the accuracy is adequate for the purpose intended. Likewise, "uncertainty" can represent experimental variability, variability of the model's parameters but also inappropriate modeling rules in regions of the design / operational space where experiments are not available.

An alternative to the theory of probability is applied to the problem of assessing the robustness of model predictions to sources of uncertainty. The analysis technique is based on the theory of information-gap, which models the clustering of uncertain events in embedded convex sets instead of assuming a probability structure.[3] Unlike other theories developed to represent uncertainty, information-gap does not assume probability density functions (which the theory of probability does) or membership functions (which fuzzy logic does). It is therefore appropriate in cases where limited data sets are available. The main disadvantage of information-gap is that the efficiency of sampling techniques cannot be exploited because no probability structure is assumed. Instead, the robustness of a decision with respect to uncertainty is studied by solving a sequence of optimization problems, which becomes computationally expensive as the number of decision and uncertainty variables increases.

The concepts are illustrated with the propagation of a transient impact through a layer of hyper-elastic material.[4] The numerical model includes a softening of the hyper-elastic material's constitutive law and contact dynamics at the interface between metallic and crushable materials. Although computationally expensive, it is demonstrated that the information-gap reasoning can greatly enhance our understanding of a moderately complex system when the theory of probability cannot be applied.

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[2]Doebling, S.W., "Structural Dynamics Model Validation: Pushing the Envelope," *International Conference on Structural Dynamics Modeling: Test, Analysis, Correlation and Validation*, Invited keynote presentation, Madeira Island, Portugal, June 3-5, 2002.

[3]Ben-Haim, Y., **Information-Gap Decision Theory: Decisions Under Severe Uncertainty**, Series on Decision and Risk, Academic Press, 2001.

[4]Hemez, F., Wilson, A., Doebling, S., "Design of Computer Experiments for Improving an Impact Test Simulation," *19th International Modal Analysis Conference,* Kissimmee, FL, Feb. 5-8, 2001, pp. 977-985.