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APPLICATION OF STATISTICAL ENERGY ANALYSIS (SEA) TO A PASSENGER VEHICLE: COMBINING ANALYTICAL AND TEST-BASED PREDICTION IN A HYBRID MODEL

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1. INTRODUCTION

SEA-based [1] simulation of automobile interior noise has been investigated in a variety of companies as suggested by recent papers [2], [3]. This includes Test-Based SEA, an experimental approach to SEA [4] that is often referred to as Energy Flow Analysis (EFA). Results of analytic and test-based modeling of the same vehicle were compared in [5].

In this paper, we describe how analytic and test-based models can be compared in detail and also combined into a hybrid model, in order to best utilize the strengths of the analytical and experimental approaches.The EFA model of the vehicle is presented in a joint paper [6].

2. COMPATIBILITY BETWEEN EFA AND SEA MODELS

In order to be compared or combined, experimental and analytical representations of the vehicle must be compatible. This requires some investigation, since there are some obvious differences between the two approaches.

Coupling Loss Factor (CLF)

Test-based CLFs are measured in both directions and therefore the test-based power balance matrix solution does not explicitly rely on subsystem modal densities as in analytical SEA [5]. Nevertheless measured and calculated CLFs can be compared on a one-to-one basis, as long as the subsystem energies from which the test-based CLFs are derived are correctly evaluated. For a structural subsystem, the energy is actually obtained from $E = M_{eq} < V^2 >$, where $\langle V^2 \rangle$ is the space-average square velocity and M_{eq} is the measured Equivalent Mass [4]. It is introduced to insure that measurement of velocity at discrete locations on the subsystem leads to a correct estimate of the average energy of the subsystem in each frequency band of interest.

Of course, measured and calculated CLFs may only be compared if the connected subsystems are defined with the same boundaries in both models.

Subsystem Boundaries

For practical reasons, the test-based approach tends to break down the vehicle into large size subsystems [4]. In analytical SEA, it is possible and sometimes helpful to subdivide the structure in more subsystems. Unfortunately, this renders the comparison to test results more difficult and therefore is not recommended in the early stages of the comparison process.

Energy, Vibration Level & Sound Pressure Level

Assuming consistent subsystem boundaries and adequate measurement procedures, subsystem energy levels predicted by the SEA and EFA models can be compared. This comparison can be extended to velocity or sound pressure level (SPL), provided that the same conversion from energy is applied. Effectively this means introducing measured equivalent masses and volumes in the analytical SEA model. The justification for doing so is that the analytical model is correlated against a discreet set of measurements, which is not necessarily a correct average of the measured velocity or SPL.

3. METHODOLOGY FOR HYBRID MODELING

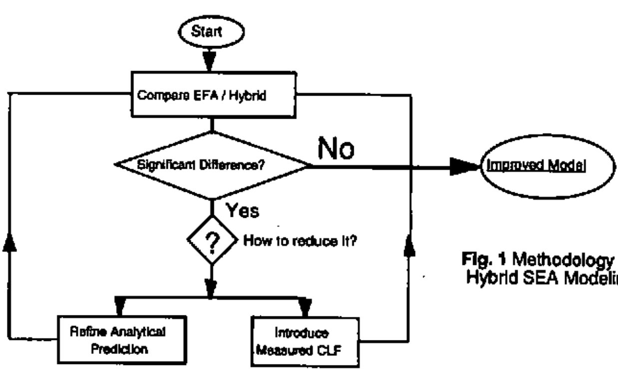

Fig. 1 Methodology for Hybrid SEA Modeling

The overall objective of hybrid SEA is to combine the strengths of test-based and analytical SEA. Test-based SEA is particularly suited to complex structural systems while analytical SEA provides detailed design information and is a real-time simulation tool that can be fully integrated into the CAE process. Following the methodology illustrated in Fig. 1, test-based and analytical results are compared. Differences are analyzed in order to identify the controlling factors (for example a specific CLF) and gain some understanding of the physics involved. Using the test results as a guide, there are two ways to go when differences are detected: improve the analytical model through a refinement exercise (left loop), or introduce test-derived CLFs in the analytical model, which then becomes, by definition, hybrid (right loop). Note that the refinement exercise (left loop) is in essence similar to the correlation exercise based on Modal Testing that Finite Element analysts are familiar with.

4. RESULTS

Analytical and Test-based Models

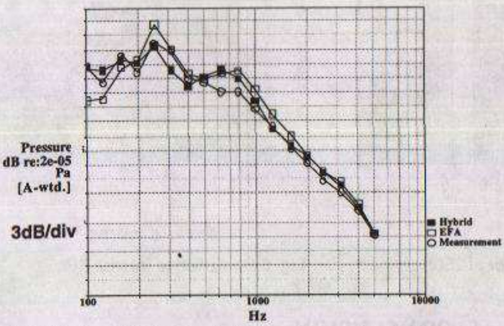

Fig. 2 Interior SPL for Constant Speed Operating Condition

Fig. 2 shows good correlation between measurement, test-based and analytical predictions. Nevertheless, a detailed analysis of the transmission paths shows that although predictions are similar in the 800Hz band (air-borne transmission dominates), hybrid modeling should be used to improve the prediction in the 250Hz band (Fig. 3).

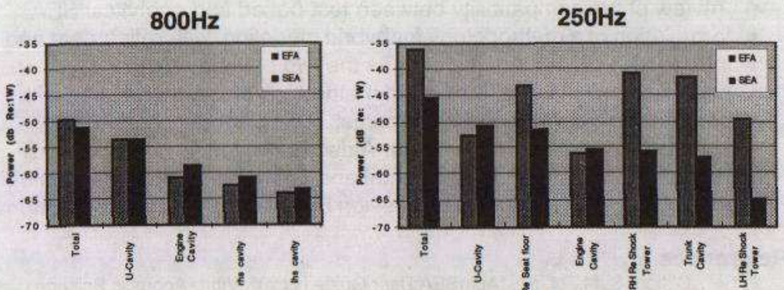

Fig. 3 Power Inputs to Interior at 800Hz and 250Hz: EFA/ SEA

Hybrid Model

Going through the steps described in Fig. 1 (right loop), the critical CLFs are identified and replaced in the analytical model by EFA data. The new hybrid model contains six test-derived CLFs and shows good correlation to the EFA prediction (Fig. 4). The validated hybrid model can now be used to simulate vehicle modifications. Additional layers of acoustic trim are introduced in a number of locations and the modified vehicle is tested on the road [6]. Figure 5 shows that EFA and hybrid models accurately predict the effect of the added trim on interior SPL. This confirms the quality of the EFA and hybrid models, as well as of the analytical modeling of trim [7].

Refined Model

During modeling, comparison of test data and analytical results helped review and adjust analytical parameters. Nevertheless, *refinement* of the model (left loop of Fig. 1) actually goes beyond *adjustment*, since it consists of breaking down one or more of the subsystems that appear to play a critical role. This approach was investigated but it was concluded that at 250Hz (a low frequency for this SEA application), the hybrid model performs better.

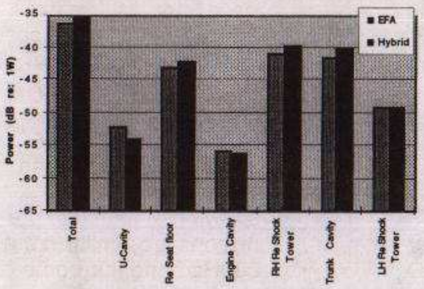

Fig. 4 Power Inputs to Interior at 250Hz

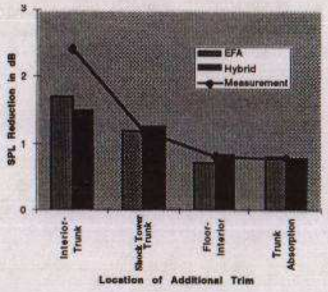

Fig. 5 Reduction in Interior SPL

5. CONCLUSION

The main achievements of the work described in this paper are:

- review of the compatibility between test-based and analytical SEA,
- formulation of a methodology for hybrid modeling, with refinement and introduction of test-derived data as the two options,
- practical application of the hybrid method to vehicle prototyping with correlation to on-road measurements,
- integrated approach to Computer Aided Engineering for Noise and Vibration, where both experimental and analytical representations of the vehicle are available to the Design Engineer at the click of a button.

References

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