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VIBROACOUSTICS IN AUTOMOTIVE

A DIFFERENT APPROACH TO NOISE PROBLEM SOLVING IN AUTOMOTIVE

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SUMMARY

Although vehicles noise sources are well known, their contribution to the resulting overall noise in the cabin or to an external pass-by are very often a matter of intuition rather than a real scientific approach. Most of the efforts carried out in the recent years have tried to introduce simulation methods beside of the different methods of investigation based on data acquisition and analysis. Instead of modelling the complete structure and related components it comes out that it is more efficient to simplify and eliminate everything which is not directly concerning the specific noise problem and try to model "the problem" alone. The simplified approach may become much faster and the results are more easily checked out if compared to a general approach to the complete structure, but the construction of the "problem model" requires a preliminary investigation, cause-effect assumptions and new simulation tools.

INTRODUCTION

A Complete Acoustic Modelling Design of a vehicle can be still considered as a dream of many car manufacturers; nevertheless, the acoustic modelling approach is widely used and is becoming more and more important as a design tool with the goal of reducing developing time.

The general misunderstanding of the acoustic modelling is to consider it as a "magic" tool which should give answers to any possible question, but expecting this is a real dream, acoustic and vibration modelling cannot give exact answers so far but "very important pieces of advice", and it is from this concepts that the acoustic modelling should be implemented as a problem solving tool in the design and prototyping stage.

Until recent times the designing did not take into account at all the acoustics of the vehicle since not many people do really believe in it, and on the other hand the acoustic problems appear at the prototype stage or even later. The experience of people working in the acoustic field is limited to problems arising from a real thing and very rarely is used at the designing stage; someone says that designers and experimental people cannot understand eachother. But this divide must change because the acoustic problems can be considered from the beginning if the experimental people can get aquainted with FEM models, and be solved more easily if the designing people can understand what a measurement report really means.

That is why an acoustic modelling should be used together with the prototype development as an additional tool oriented to problem solving and the procedure can follow some principal steps:

<u>design stage:</u>

1. obtain a reduced FEM model for acoustics
2. use BEM or SEA methods to extimate the noise levels with extimated input forces
3. figure out if there is any serious problems at the design stage

<u>prototype stage:</u>

1. get experimental data from the prototype and isolate the noise problems
2. obtain circled models for each problems and check input forces amplitude
3. try possible solutions and simulate the expected results

4. verify the solutions on the prototype

5. use the experimental result to refine the solution

THE DESIGN APPROACH

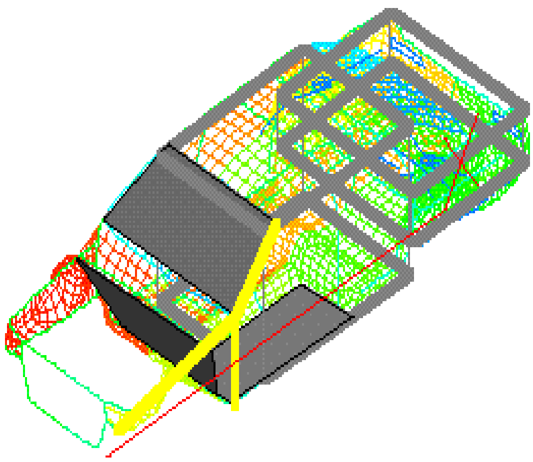
The following is a case story taken from Vibro-Acoustics Science Inc. Application Note describing the application of AUTOSEA software package for simulation of the interior car noise.

Considering the cabin interior noise, the typical questions to be answered are:

- What is the noise level in the car?
- What are the main sources and transmission paths?
- How can we reduce the noise level?

In order to answer those questions it is necessary to import the FEM model of the car (from NASTRAN, I-DEAS, ecc); this is a coarse mesh typical of a “concept stage” model which may results in about 150.000 elements, and it needs to be reduced to approximately 50.000 elements. The reduced model has to be revised, solved and then it is necessary to check whether the original characteristic are maintained (modes shape) or not.

The reduced model can now be used to extimate the noise level in one or more receiving position inside the cabin by apply aVibroacoustic method depending of the frequency range of interest. There are basically 2 methods: the FEM-BEM (Finite and Boundary Elements) up to 200 Hz or SEA (Statistical Energy Analysis) starting at 200 Hz and above. The FEM-BEM method can be applied to structure-borne and air-borne paths but due to the quick arising of the modes density the solution is complex and it requires too many elements, and it becomes interesting to apply instead the SEA method which in turn gives better results as the modal density is increased. On the figure there is a vehicle with sub-systems circled and isolated with the SEA approach



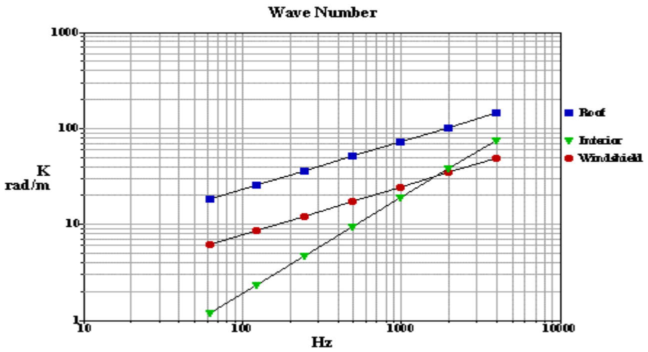
Correlation techniques have to be used with the FEM-BEM methods, between vibrations and sounds, to identify sources and transmission paths while possible noise reduction techniques can be checked out with the possible results.

With SEA approach it is used instead an energy transfer calculation to identify the contribution of each sources and propagation paths efficiency.

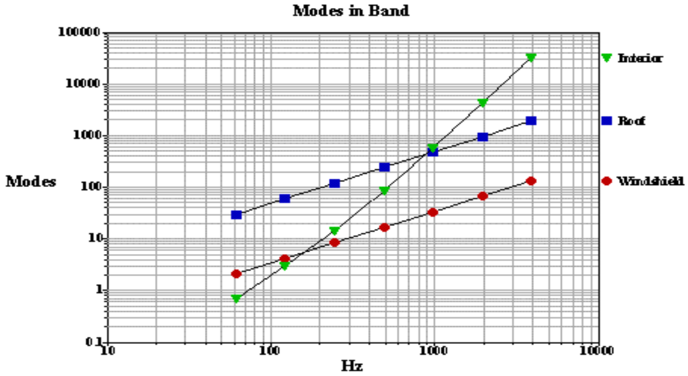
Complex problems can be solved more efficiently by looking at each of them step by step. We will show the use of the AUTOSEA package in a specific application concerning the roof noise problem due to aerodynamic pressure.

We first import the FEM model and store material and beam section properties in the databases, than we reduce the geometry complexity by making only the NASTRAN roof elements and all the SEA substructures, except for the windshield, visible; we add than a Plate Flexural to the SEA model to represent the roof.

Let is see now how with the SEA approach and in few steps we may arrive to some results:

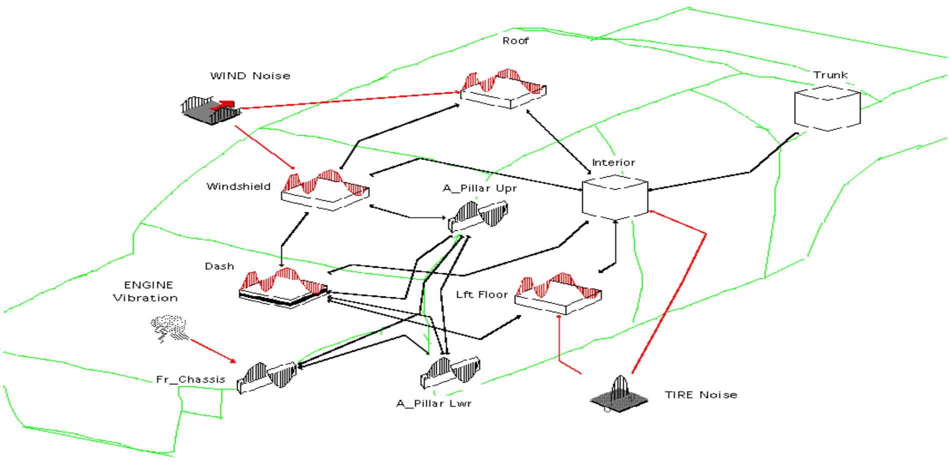


- group the Roof, Windshield and Interior cavity and observe that the number of modes in a band, for the acoustic cavity is increasing very rapidly,

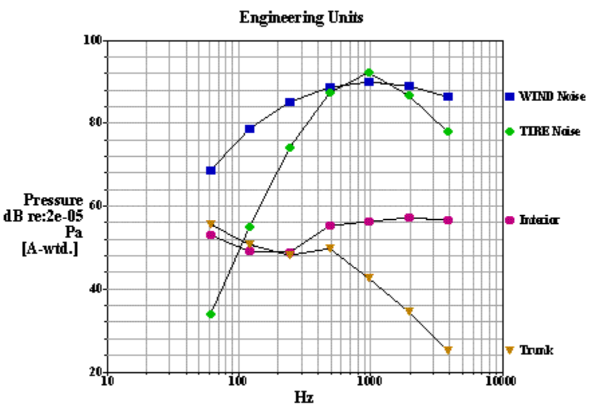


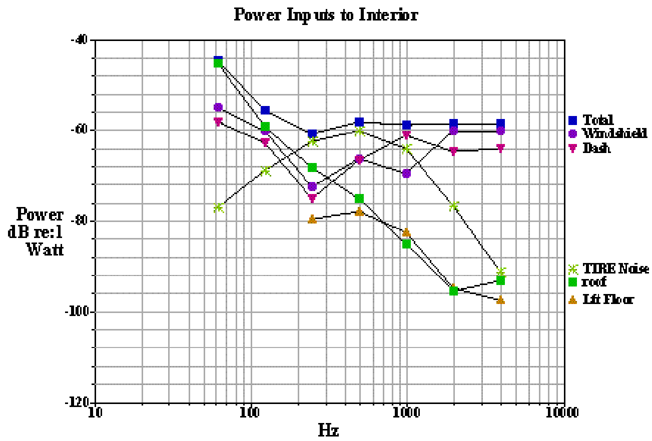
- graph the Wavenumber for the selected subsystems and observe that the glass coincidence frequency is much lower than the roof's. The windshield is an efficient radiator on a large frequency band.

Connect the Roof and Windshield subsystems, their angle is close to a normal angle and therefore the power is transmitted via moments only. Connect the Roof and Interior subsystems, the radiation efficiency of the roof panel is dependent on factors like: the clamped boundaries and normal baffles that increase it and the roofliner that decreases it. The effect of the roofliner on radiation efficiency can be analytically modelled using SEA's approach, or alternatively test data can be imported in the model.

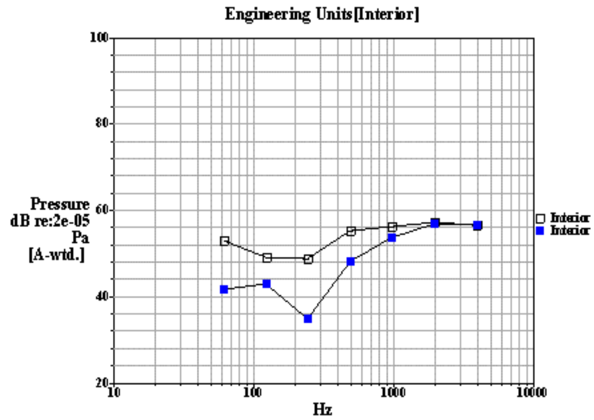


Represent the wind (aerodynamic) pressure source on the vehicle roof by connecting the power source to the



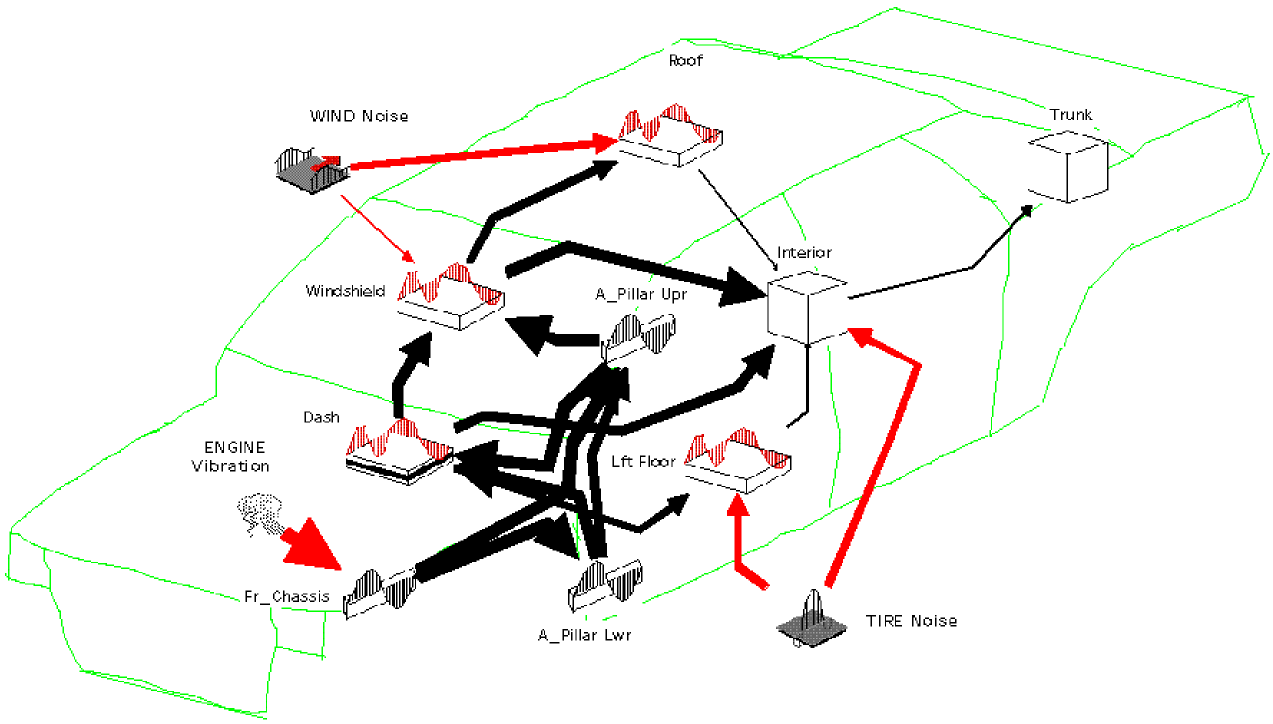


Roof subsystem. The wind pressure spectrum can be determined either by wind tunnel or on-road measurements at the roof surface and imported, or calculate as a default spectrum. The power input into the Roof due to wind noise is large at low frequencies and decreases rapidly due to the divergence between structural wavenumber and convection wavenumber. Note that other sources in the model are the engine structure-borne noise represented by measured vibration on the vehicle front rail and the tire air-borne noise represented by a diffuse SPL measured under the car on the bottom surface of the floor panel. The SEA Network looks like this.



By solving the network in order to get the predictable A-weighted SPL in the car, in the trunk, under the car, and outside the car the windshield and roof, one may observe that the higher levels in a A-weighted sense are for frequencies above 500Hz. If we look now at the Power Inputs to the vehicle interior for the multiple source problem we will notice that tire noise is dominant between 250Hz and 1Khz, but that at higher frequencies windshield radiation is responsible for noise inside the vehicle and we have now to understand what causes the windshield to vibrate.

The first approach is to perform a "Source Ranking" evaluation by freezing the Interior SPL, then



disconnecting the Wind Noise and Tire Noise sources and re-solve everything. It comes out that the high frequency windshield radiation into the car is due to structural excitation from engine vibrations.

By reconnecting the Wind Noise and Tire Noise sources (the input for the floor mass law is 0.73m² and 4.5kg) and re-solving to obtain the Energy Flow at 2KHz we find out (as expected) that Windshield and Dash are the main contributors to interior noise, but now we also have information on the structural paths through the lower and upper pillars.

Tire noise transmission in the 500Hz-2KHz frequency range can be reduced by the addition of a floor trim. The 3-layer sample has to be created in the database ("Floor Trim") and added to the connector between the Tire Noise source and the Interior. The composition of the package can be tested and tuned to obtain the maximum effect in the desired frequency bands. Double-wall resonance effects may increase Interior SPL in certain frequency bands, such as in this case in the 250Hz band. Other design solutions may be tested on this model, for example:

- optimization of floor trim,
- optimization of Interior absorption (also using SEA's approach),
- structural modifications on the front-end of the car to reduce the high frequency noise due to engine vibration.

THE PROTOTYPE APPROACH

Once the prototype or a part of it becomes available some preliminary investigations may start and the standardized measurement procedures can be extended behoind the classical Data Acquisition and Frequency Analysis to the "listening" session of the noise inside the cabin in order to couple the technical understanding of the data with a physiological sensing on what is going on.

The listening is the key point and this feature can be added to the measurements by using the HEAD recording system with artificial Head or BHM (Binaural Measurement Microphone – by HEAD Acoustics).

Looking at the time-frequency rapresentation of the noise events while listening to them gives the possibility to the acoustic engineer to focuse his attention to some specific noise by enhancing it or suppressing others spurious phenomena, using the SQ-LAB from HEAD Acoustics. For instance it may be carried out a synchronous listening comparison between the original noise recorded and the same one filtered; filtering means to decrease the amplitude of a certain component and feel the changing in the sound. This sort of sensing analysis is of tremendous help in establishing the cause of the effect, identifying single noise sources and possible propagation paths through the structure and the medium.

Usual tests are carried out both on accelerating vehicle and on stationary conditions. The first step is usually the test road which should normally show if and where are problems; i.e. cabin maximum A-level, critical zones of booming effects, noise components, rpm or speed critical conditions, sound quality, etc.

The analysis and "listening" of the test road will give the hints to define a test plant in which the "problems" are identified and listed, priorities and investigation steps are also established.

Investigations have to be performed first on the acoustic model since their validity can be verified faster and the experimental verification could take place with more confidence and understanding. Probably the acoustic model manipulation cannot always give results since it is not a perfect and complete simulation tool, but quite often gives pieces of advice to direct the experimental part of the development.

It is this "parallel" investigation on the acoustic model and on the prototype with all bi-lateral exchange of informations that speeds up the search for a possible solution and its verification to the specific noise problem.

Just to give a general overview of what means experimental test directed from acoustic mdels, we will detailed some typical tasks performed on a real case for a light commercial truck.

Modal Analysis

Experimental Modal Analysis of the complete vehicle it is not an easy task and it is not very useful to check the FEM model. The problem is the suspension and the excitation of the structure which in turn shows high damping for higher modes and non-linearities for lower ones. Since the acoustic model reports the type of problems to be investigated, it is much more efficient to perform a local modal test on sub-structure: windows, roof, doors, etc. keeping the excitation points as closest as possible to the real case, i.e. engine or cabin suspensions, roof distributed force, etc.

Acoustic modes

The experimental determination of the Acoustic Modes inside the cabin has 2 goals:

- check for the theoretical modes

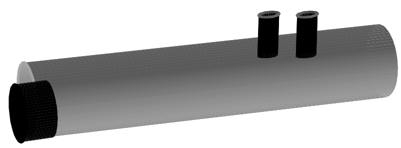
in order to refine the acoutic model

- measuring the damping

determining experimentally the amount of damping due to acoustic materials, dashboard and seats.

The problem here is concerning the acoustic excitation of the cavity since the use of some sort of loudspeaker does not allow to receive any information on the excitation force, i.e. the system input. One possibility is to use a device based on the Standing Wave Tube, normally used for determining the materials acoustic properties.

The tube is mounted with an open end to the window (open) of the vehicle cabin and has a loudspeaker on the other end. Two microphones are mounted along the longitudinal axe. By measuring the transfer function between the 2 microphones it is possible to derive the acoustic energy flowing through the other end and going into the cabin.



Input Forces

Road test are used both for noise and vibration measurements; while the noise measurements are mostly concerning the noise level in the cabin, the vibration measurements on the engine suspension give amplitude and spectra of the input forces for the structure-borne noise. By inserting the measured force in the acoustic model it tunes more precisely the noise calculation due to input vibrations.

For the air-borne input forces, i.e. the acoustic radiation of the engine, it is necessary a different approach depending whether the FEM model of engine (acoustically speaking) is available or not. In most cases this information is not available neither at the designing or at the prototype stage and it will be very interesting to determine experimentally the acoustic model for the engine. The procedure is in reality very self explained: with a mapping of the hypothetical sound pressure level SPL on an hipothetical surface around a test engine it is possible to define the sound pressure distribution and the phase relationship vs. Frequency. By a backward least square estimate one can derive an equivalent acoustic model of the sound source when gives the same distribution. The acoustic model of an engine required something like 10-20 elementary pistons with radiating area weighted with the engine geometry elements. The procedure is very easy to understand but it requires a good skill in the execution: first of all it is necessary to set-up a multichannel measurements system with a number of microphones sufficient to get the phase relationship plus some reference microphone points; second, one has to decide the critical rpm as a stationary condition for the measurement, and this information can only be derived from the analysis of the road tests and the “listening” session described previously.

Once again this information can be inserted in the acoustic model of the vehicle as a “real” air-borne input force and the noise level inside the cabin recalculated.

CONCLUSIONS

The acoustic study of a vehicle is rather a team task and not just a matter of an individual feeling and expertise applied. Several approaches are possible either at the design as well as at prototype stages and there are also a lot of possibilities to investigate the noise emitted from vehicles but definitely an exact procedure for each topics cannot exist.

If anyone want to take advantage from what the modern calculator systems may offer he should follow some sort of minimalistic approach in order to reduce the complexity of a general project to a set of individual problems: try not to get lost at looking at the vehicle as a total problem, it is the usual question on "looking at the forest instead of looking at the trees".

From the very beginning of the design stage for instance, the acoustics of the vehicle should be introduced with simplified approaches and as soon as protypes become available the acoustic model has to be tuned with experimental data. Once that noise problems are identified experimentally the possible solutions should be tested numerically on the tuned acoustic model since it is much faster and cheaper than a practical modification on the vehicle itself. Those modifications can be done later on the basis of the model responses.

It is this kind of data exchange between experimental and modelling people which can gives the best results and the rationale development of a vehicle under the acoustics point of view.