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Technical Engineering & Research in Acoustics

2008_10_History of update SEA-TEST.doc

Summary

Presentation

InterAC Experimental SEA Software: SEA-XP/SEA-TEST have been evolving continuously for the last past ten years to fit with the complexity of industrial design. This software is mainly an evolution of early routines developed from 1991 by Dr. G. Borello to build SEA model of industrial engines. With the help of SEP (Société d'Etudes et de Propulsion) that has been designing the cryogenic rocket engine of Ariane 5, Vulcain, these routines have been turned progressively into a full operational software combining both acquisition and post-processing for a maximum of performance.

Starting from decomposition into subsystems of the system to be analyzed, **SEA-XP/SEA-TEST** is solving the active power balanced equations by measuring transfer acceleration and input power. More precisely the measured quantities are FRF's and input conductances as all accelerations are stored in FRF format and only the real part of the normalized input power/force² is used in the power equilibrium.

Here below, one of the first **SEA-XP/SEA-TEST** application where the experimental power balanced equations have been solved to built a hybrid SEA model of the Vulcain. The analytical formulations where provided by the Dr. Borello's SEA software EARTHS, specifically designed to model the Vulcain and completed and validated by import of experimental SEA parameters.

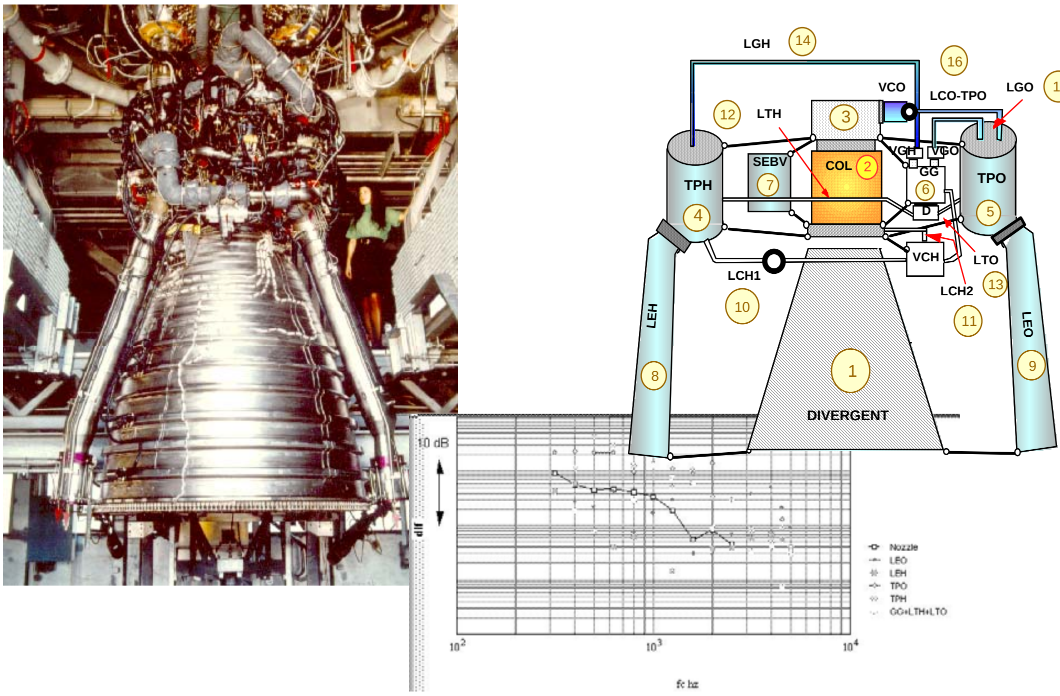


Figure 1 : The SEA Vulcain model built in 91 with the help of original SEA-XP/SEA-TEST routines and related

Why measuring DLF and CLF?

Separating internal and coupling losses

In most cases, the damping loss factors (DLF) of industrial structures cannot be computed theoretically. They are also depending on the assembly and thus cannot be determined from individual tests.

More of it, simple tests such as decay rate measurement cannot provide good enough estimates of subsystem DLF. In fact the DLF of a subsystem in a coupled model is related to the power loss that is intrinsically dissipated within this subsystem and which is not related directly to the decay rate of its impulse response. The decay rate is only proportional to the total loss related to a given subsystem i.e. sum of the intrinsic power loss within this subsystem and to the power dissipated in the coupling (that escapes to the other coupled subsystems). Thus the decay rate includes information about both intrinsic power loss and coupling loss.

The power losses into the coupling between subsystems are characterized by the related coupling loss factors (CLF).

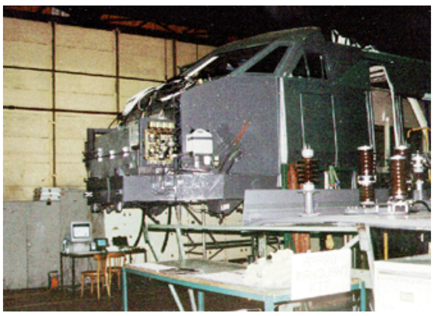
The CLF level is depending upon the mechanical connection between subsystems.

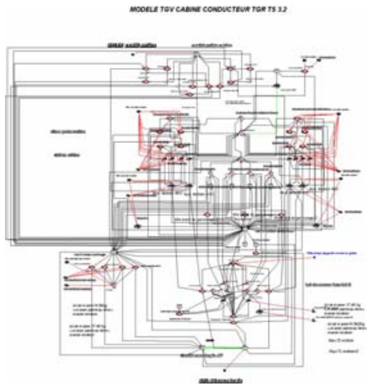
To compute these coefficients in the high frequency domain, analytical SEA heavily relies on simplified hypothesis: ideal diffusion of energy, plane wave assumption, simple line or point connected junctions of homogeneous simple plates or shells. On real structures, junctions are far ahead in term of complexity.

Experimental SEA, by measuring all transfer velocities and input conductances from a set of simple impact or acoustic tests, is able to identify both intrinsic DLF and the CLF between any subsystems. The subsystems must exhibit local modal behavior in the frequency range of interest for the inverse problem identification to be successful and is de facto a “high frequency measurement” technique.

SEA model of complex industrial machines can thus be built with the help of this technology.

Using the **SEA-XP/SEA-TEST** estimates of CLF, it is possible to tune simple adequate theoretical models of junctions in order to perform parametric changes and noise reduction analysis. As shown here below, powerful SEA models of complex systems such as the French High Speed Train (HST) were built with accuracy using hybridization of analytical and experimental loss factors.





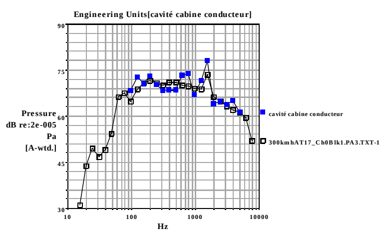


Figure 2: SEA model of the driver's cabin of French HST train for prediction of the airborne and structure-borne sound transmission (on the right prediction at 300 km/h and measurement in cabin

In cooperation with Alstom, the French train manufacturer, many train vehicles (cabin or coaches) have been modeled using experimental SEA leading to fine understanding of system behavior.

Analyzing subsystem polymorphism

Experimental SEA helps in understanding the polymorphism of subsystems (evolution of dynamical behaviour vs. frequency).

When applying experimental and analytical SEA to car modelling, it rapidly comes to an end that the frequency range of interest (100-2000 Hz) was very difficult to be successfully covered using only analytical description of subsystems.

Looking on the rear pillar shape of a car roof (Figure 3), it can be clearly seen that it is not easy to confine its SEA description in term of simple analytical beam or plate.

From experimental SEA, we learn about this subsystem by measuring both input conductance and CLF. It appears that this subsystem can be seen as a SEA beam at low frequency and as a SEA plate at higher frequency. The transition frequency domain just lies in the 800-1000 Hz.

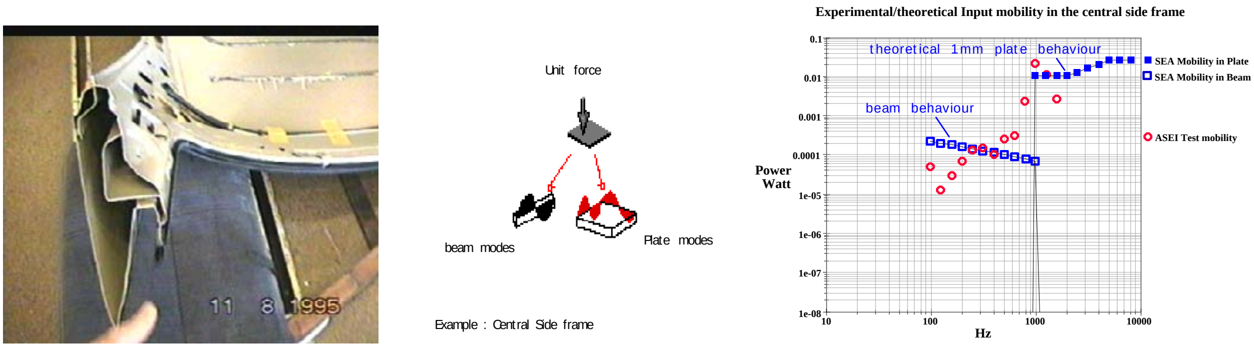


Figure 3: Analyzing subsystem polymorphism of car subsystem with experimental SEA

Most of the SEA subsystems of a car exhibit this dramatic change of dynamical behavior in this mid-frequency region, leading to difficulty in applying a "static" analytical description for each of them as required in commercial analytical SEA software.

Experimental SEA was thus used to find "equivalent" SEA analytical representation that could fit to the observed dynamical behavior.

SEA models for non-homogenous structures

Experimental SEA is very useful to understand how non-homogeneous subsystems behave.

Non-homogeneous subsystems are characterized by some non constant parameters that can vary within the subsystem domain: non constant thickness, radius of curvature, material…

A car is typically made of many non-homogeneous subsystems.

Classical analytical SEA is ideal for homogeneous subsystems but how to derive an analytical representation of a shell with a non constant radius of curvature as an example?

Experimental SEA is using a multi-transducer approach to solve elegantly this problem.

In place of describing the subsystem by a single power balanced equation, referenced to a particular excitation (or to a particular transducer in reciprocal measurement), it uses as many power balanced equations as required with several reference excitation spread at various locations of the subsystem. Using more equations than unknowns in the solve process, it is possible to find a best-fitted experimental set of SEA parameters to characterized this non-homogeneous subsystem from the pseudo-inverse of the energy matrix (with a singular value decomposition or SVD solver).

Non-homogeneous subsystems are also characterized by high variability of velocity when scanning the subsystem domain. All estimates of measured energy and power are thus affected by some variance depending upon subsystem complexity.

When simply inverting the transferred energy matrix once, some SEA parameters can be negative on output and not really representative of the real statistical behavior of the subsystem. A Monte-Carlo procedure has been introduced in the solve process to overcome SEA parameter dispersion:
-when recording the data, variance is computed for all inputs,
-when solving, the input data set is perturbed, following related variance of each of the input and the output set of SEA parameters is averaged with previous results obtained for another perturbation of the input data set
-the solve process can be run in loops several thousand of time in order to derive statistic and variance on output. Some solution sets that are obviously non physical can thus be rejected from the averaged solution (i.e. SEA sets that incorporates too many negative CLF of DLF values).
-the SEA loss matrix final solution can be characterized by a performance index, providing confidence in the result.

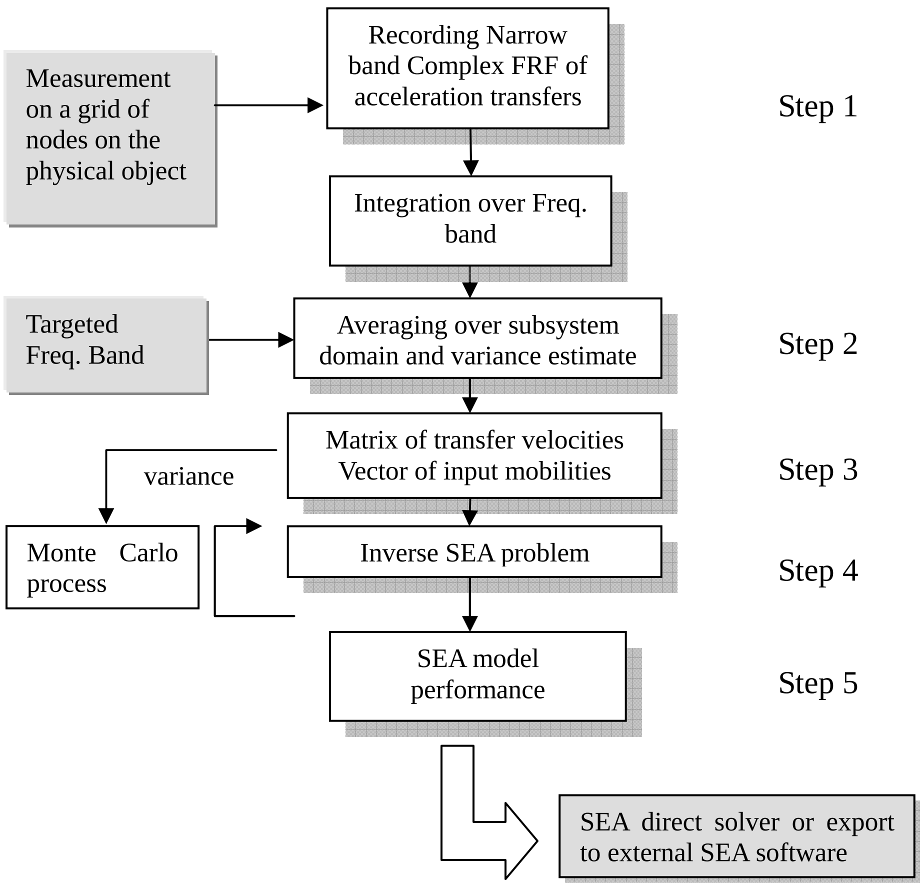


Figure 4: The data flow of experimental SEA

The velocity to energy conversion is performed through an “equivalent mass” term which is determined experimentally from the analysis of the decay rate of impulse responses of recorded FRF. This mass term is generally frequency-dependant as we deal with complex subsystems. The mass is nearly independent from frequency only for homogeneous simple systems. The use of equivalent mass in SEA is greatly improving dynamical behavior understanding and its computation does not require any additional measurement as it is fully automated in **SEA-XP/SEA-TEST**.

Acoustic and structural coupling

Most of the uncertainty in SEA models is contained in structural subsystems and **SEA-XP/SEA-TEST** was designed from the beginning to focus on structure borne sound transmission. Nevertheless, a full acoustic-to-structure analysis has been included in the software in the mid-nineties.

Within **SEA-XP/SEA-TEST**, the only difference between acoustic SEA subsystems and structural subsystems is the type of recorded data. Generally, pressure measurement is used for acoustics and acceleration for structures. In **SEA-XP/SEA-TEST**, the data type for acoustics is a FRF computed as “pressure signal /reference signal”. When computing the mean squared transfer velocity from the FRF, the software automatically converts all acoustic FRF into velocity spectra, using an impedance term (the acoustic impedance) that is defined for each record.

After averaging into squared velocity, there is no more difference between cavity and structures in the data set.

Various problems can be addressed by experimental SEA, from pure cavity coupling to full vibroacoustic analysis.

Example 1: Sound radiation of a car at 7.5 m and analysis of the sensitivity of absorption changes in the cavities below bonnet

The experimental SEA is used to determine optimal split of the acoustic space surrounding the engine, associated coupling apertures and intrinsic DLF values. The final model is a hybrid experimental-analytical SEA model able to reproduce within a few dB the noise radiated at 7.5 m outside the vehicle

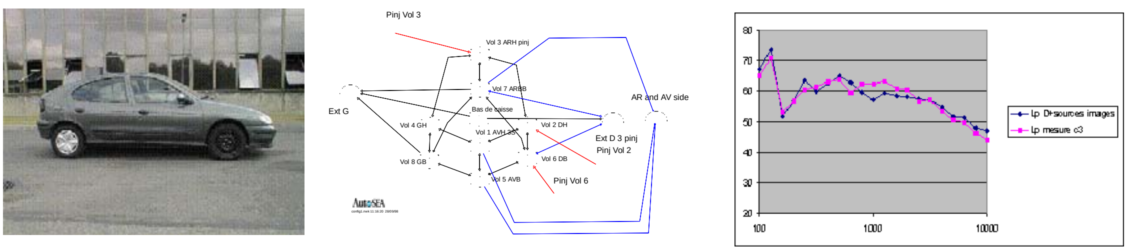


Figure 5: Prediction of sound radiation at 7.5m from the engine using hybrid SEA modeling and comparison of SEA predicted SPL (from engine radiated power) and measured SPL at 7.5 m

Example 2: Dashboard radiation

A full experimental model of a dashboard coupled with emitter and receiver cavities is created to analyze energy transmission paths between the two cavities and to predict the effects of changing trim configurations.

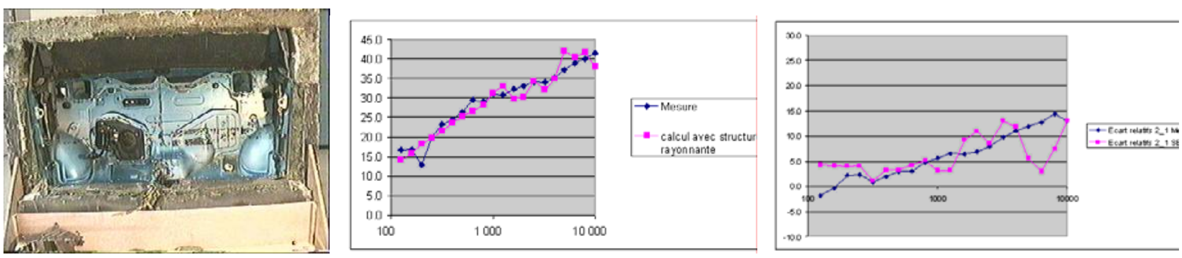


Figure 6: Prediction of dashboard transmission loss using experimental SEA model and comparison between relative change predicted from the model and direct measurement for two different configurations

Exporting experimental SEA model to analytical SEA software

Experimental SEA is a good complement of analytical SEA software. Analytical prediction can be validated for all parameters and experimental description can be substituted to analytical one when the subsystem complexity is not suitable with the simple analytical libraries.

AutoSEA1.5 was the first version of AutoSEA that was supporting import of experimental SEA data.

In fact from **SEA-XP/SEA-TEST**, you can export and open your experimental model to AutoSEA1.5 without any extra work using the neutral file format.

If an analytical AutoSEA1 model already exists, you can simply choose to write directly the experimental SEA information in the Neutral file of the analytical model. When subsystem names are identical in the experimental model and the analytical one, experimental SEA parameters of selected exported subsystems are allocated to the related SEA subsystems.

The first release of AutoSEA2 (2.0) was not compatible with experimental SEA. InterAC and VASCI (AutoSEA developers) have developed a common way of exchanging data between the software using the Universal file format (UFF). This was implemented in the AutoSEA2.1 version and available in the **SEA-XP/SEA-TEST** 2.1 version as well.

This functionality is currently the way to transfer data from **SEA-XP/SEA-TEST** to AutoSEA2 latest release.

The way it works is simple. In AutoSEA2, you can define alias names for each subsystem. The alias name of an AutoSEA2 subsystem should be the same than the related **SEA-XP/SEA-TEST** subsystem.

From **SEA-XP/SEA-TEST** you import all CLF, DLF information in a single UFF file.

From AutoSEA2, you first export this file in the database of the software then use the AutoSEA2 “tools” function to simply allocate the experimental coefficients to the right subsystems.

Review of SEA-TEST evolution

Version 1.0 (October 2006)

- Experimental SEA with imported measurements

Version 2007-03 (August 2007)

Adding functionalities

- Auto-Rev module and documentation

Bugs fixed and enhancements

Experimental SEA menu All Simplified CLF

-Dialog box progress sometimes locked: fixed
-Some CLF are not correctly allocated in the matrix: fixed
-Text property dialog box not properly closed, disabling closing of Experimental SEA routine: fixed

Experimental SEA menu Import from model

-Frequency shift was sometimes observed in the imported data: changed in management of index and frequency choice : problem fixed

Graph Export to UNV or to Excel

-First frequency of frequency spectrum was different from other leading to miscomputation of frequency step when exporting (fixed)

Auto-substructuration

-Cavities were not correctly detected in Auto-substructuration: fixed

- Reference Correlation matrix algorithm revisited now with two options : fast clusterization and genetic

Edit test specimen

-All subsystems parameters, surface, volume and mass, initialized to 1
-Adding edition of test specimen properties in the project manager

Experimental SEA solver

-Improvement of Loss matrix optimizer: performance index now computed by same routine, adding local global performance index and extra menu
-Import from model: now loss factors from subsystems with same name can be averaged between imported and targeted models
-New subsystem edition pane (parallel editing)
-Possible manual import of 1/3 octave spectrum in any item of the experimental SEA model

Version 2007-04 (November 2007)

Adding functionalities

- V_R protocol for non homogeneous system and theory
- Creating geometry from FE exported data

Bugs fixed and enhancements

- Time reverberation in AutoRev

Version 2008-1 (April 2008)

Updating the user's guide to explain "reduced velocity" solve

Version 2008-1.1 (July 2008)

- Change licensing protection from hasp key to license file
- AutoRev reverberation time analysis can be extended to very low frequency (limit 1 Hz)

Version 2008-2 (October 2008)

- Automated support is added for P/Q transfers, meaning that the post-processing will be entirely automatic up to SEA model creation, avoiding mistakes like using ill-defined masses
- Multiple file selection for importing file
- Improved dialog box for "Subsystem Property Characteristic" input
- Possibility to modify manually the sign of a particular FRF of the database using local right-button menu when selecting a record.
- Updating the user-guide to give more practical details on how to measure power, full documentation on using P/Q transfer functions and overview of the various test protocols