Application of Statistical Energy Analysis on a car: from the vehicle modeling to parts targeting

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ABSTRACT
Original equipment manufacturers generally set their acoustic performance goals at the beginning of a new car project. For the sake of practicability, it is necessary to translate these global targets into components targets. The aim of this paper is to give an overview of the application of SEA on a vehicle in the perspective of making parts targeting. First, a review showing the different steps to reach a complete SEA model is presented. The focus is on the computation of absorptions and transmission loss of the SEA panels, the approximations used and how pass-throughs are included in the model. Then the target cascading analysis (TCA) is broached. The TCA is based on the SEA model just engineered. It is an optimization procedure to minimize the difference between a target sound pressure level (SPL) and the SPL reached with improved sound package parts. Results from different projects are shown and a discussion on the handling of multi-targets is also provided.

Keywords: SEA, Panel Contribution Analysis, Target Cascading Analysis

1. INTRODUCTION
The will of original equipment manufacturers (OEM) to reduce the sound pressure level is still a primary goal. This even with the breakthrough of electric vehicles where the engine source is greatly diminished; other source excitations remain notably tyres and the turbulent air flow. The target level is set with respect to the customer reference frame, a curve in dB versus frequency for the driver’s head cavity.

There are multiple ways to achieve a target. And to assess the likelihood of each solution it is necessary to take the main goal back to a component level. This is precisely the objective of the Target Cascading Analysis (TCA). This method, based on a SEA framework, improves virtually a database composed by the part acoustic properties which are transmission loss and absorption coefficients.

The aim of this article is to give an overview of the full airborne modeling workflow including material characterization, vehicle testing, how leakages are taken into account, etc.; all in the perspective of making an airborne TCA.

Firstly, one must define the SEA model that is the stand of all calculations. The first part of this paper is dedicated to this: from a short SEA presentation, the base geometry used for simulation is discussed. Secondly, a focus is done on parts characterization. Here the approach used to estimate transmission loss and absorption by simulation is shown as well as few measurement tools. The fourth part deals with the correlation between the simulated model and measurements. It also broaches the panel contribution analysis (PCA) that sorts out the energy contribution of panels for a given cavity. Eventually, part five describes the TCA related to the validated SEA model. In particular it is shown, starting from one or several global vehicle targets, the procedure to calculate sub targets for single parts.
2. BUILDING THE SEA MODEL

2.1 A short presentation of SEA

Statistical energy analysis (SEA) is a vibroacoustic method that aims at predicting the energy transfers from one subsystem to the others. The coupling power proportionality, which is the main results of SEA, states that the power exchanged between two subsystems is proportional to the difference of their modal energies. This statement is valid as long as the SEA assumptions are fulfilled.

There is no general definition of a SEA subsystem. A subsystem is simply defined as a group of modes where the energy is equally distributed. A subsystem dissipates energy and exchanges energy with the other subsystems. The equation governing the power balance for a subsystem $i$ is

$$ P_{\text{inf},i} = P_{\text{dis},i} + \sum_j P_{i,j} $$

With $P_{\text{dis},i} = \eta_i \omega E_i$ the power dissipated and $P_{ij} = \eta_{ij} \omega N_i (E_i / N_i - E_j / N_j)$ the power transmitted from $i$ to another subsystem $j$. $E_i$ is the mean vibrational energy, $N_i$ is the number of modes, $\eta_i$ and $\eta_{ij}$ are the so-called damping loss factor (DLF) and coupling loss factor (CLF).

A comparison between a subsystem behavior and a water tank is often done (cf. Figure 1). The injected force is a constant flow source; it fills the subsystem (i.e. tank) with energy. A tank loses energy through a leak proportional to a dissipation factor. Tanks are connected and can then exchange energy. The power flow through a connection canal is proportional to the difference between two water heights $h$.

Other SEA assumptions can be discussed with this illustration:
- The injected power shall excite all modes of a subsystem; in this case we can conceive a rainy excitation coming from the tap. The drops fill the tank and cover the whole water surface. Excitations are in that case uncorrelated in time and space.
- The coupling between two subsystems is supposed to be weak. In our case it can be modeled by small diameter canals. In this way, the water escapes from one tank and no particular effect (vortex, wavelets) are observed on the water surface so that the field remains diffuse.

Of course other assumptions are necessary and cannot be so easily illustrated with the water tanks sketch. But overall, a user must be fully aware of the hypotheses when using SEA. The reader will find further details on this topic in the references [1] and [2].

Figure 1 – Water tank analogy to illustrate the power balance between three subsystems.

2.2 The topological model

It is easily perceived that a subsystem can be a structure (beam, plate, etc.) or an acoustical cavity. The acoustical cavities can either be coupled to adjacent acoustic cavities, either to structural elements. Their geometry is roughly defined with respect to their physical boundaries and the SEA assumptions. In the case of airborne propagation in a car, like for the representation of ATFs in a vehicle, the structural sub-systems can be represented by walls or panels, which contribution can be reduced to a transfer of energy between two cavities. For the case of a complex acoustic system such as the
acoustics of a car, the SEA model in the end shall be composed of a network of adjacent cavities and panels. The geometrical representation of such an SEA model is usually named “topological model” because it is a 3D assembly of entities characterized by surfaces, volumes, geometrical connections. Each of those geometrical entities corresponds to physical sub-system and carries acoustical properties. The measurement and the simulation of those properties are discussed in the next section.

Figure 2 – (From left to right) Body in white FE mesh; Hard trim and seats CAD; a topological model.

Figure 3 – (from left to right) Measurement on a door panel; Illustration of the loads on a topological model (in blue: the cavities, in yellow: the topological panels, in red: the loads).

2.2.1 Numerical information

Several geometrical input data, or a combination of them, are needed to create the SEA topological model like the finite element model of the body in white or the CADs of hard trim and seats, or even simply the digital scan of the interior surfaces. Most of that information is available at OEM after the decision of creating an SEA model based on a test vehicle. On one hand, besides the geometry of the body, the FE model contains relevant information such as metal thickness, weight. They are necessary for the subsequent evaluation of energy exchanges. For instance, the stiffening beams, which introduce impedance breaks, are determining criteria to draw the contour of a panel. Ideally a SEA panel has a homogeneous steel thickness.

On the other hand, the trim and the seats CADs are useful to properly assess the panels and cavities geometries. Such information allows identifying areas of different nature for what concerns noise transmission. This is also a key point for the definition of a panel. For instance, the windshield panel will be always separated from the roof and from the hood panels; the windows will be distinguished from the other door panels (cf. Figure 2).

2.2.2 Loads definition

The definition of the SEA panels, which are situated on the outer shell of the car, is also influenced by the repartition of the “loads”. For a start, several excitations sources are defined: engine bay, front tires, rear tires, exhaust, etc. Then, microphones are placed on every external panels and an averaged SPL is calculated for each. Figure 3 (left hand side) illustrates how the loads are measured on a door. In the end, for each excitation, each external panel receives an acoustic power associated to a fixed SPL spectrum. In this way, a panel can then be split if it has different order of magnitude excitations in different areas (cf. Figure 3, right hand side).
2.2.3 Definition of topological panels and SEA subsystems

Let’s consider for example the dash part. This part separates the engine and the passenger compartment. Due to the plurality of the excitations and the geometrical reasons (the presence of the instrumentation panel, the curvature effect of the wheel arches, the different steel thickness, etc.), this part can be split in several topological panels: waterbox, dash upper, dash lower, wheel arches, front tunnel.

In addition to that, for a practical matter, the driver side and the passenger side are separated. The two sides of a car are never perfectly identical but a customer may want to have more than one value for the predicted energy in a cavity. There are no particular physical or mathematical reasons to separate in two (Driver side - “DS” and Passenger side - “PS”) a panel or a cavity. Besides, this decision can be criticized: the separation of one SEA subsystem in two for no reasons mentioned above (impedance breaks, changes of material) goes against the assumption of weak coupling in SEA.

It is precisely here that lies the difference between an entity of the topological model (cavity or a panel) and a SEA subsystem in its own right. In an airborne SEA model, only cavities are SEA subsystems. No energy exchanges are assumed between panels meaning that we consider all SEA panels uncoupled and independent. In addition, all in all, the topological model is used for the prediction of airborne acoustic energy in the car cavities. There is no interest in knowing the modal energies of the panels. These latter are limited to the characterization of a cavity: they deliver and contribute to the dissipation of the energy. The input power is introduced by means of imposed Sound Pressure Level (SPL) at the boundary of the topological model and exterior panels act as power filters. The features of a filter are directly linked to the two intrinsic acoustical functions of the panel: the transmission and absorption coefficients.

Taking back the example of the water tank, an SEA cavity viewed by the topological model is represented by a water tank, the SEA panels are the taps (injected energy, energy dissipated) and they play also the role of the junction canals. Eventually, the dimension of the SEA problem corresponds strictly to the number of cavities implied. Figure 3 (right hand side) shows a topological model of the left hand side of a car; the cavities are in blue, the panels are in yellow and red arrows represent the acoustic loads.

Finally, the topological model contains only the geometry of the vehicle body in white and the passenger compartment. Any information about acoustic trim and acoustic loads are not part of it but they remain necessary to design the shape of each entity.

3. PARTS PERFORMANCES

3.1 Cavity - Panel - cavity : the benchmark example

If a topological model is an assembly of cavities and panels then it is useful to remind the parameters brought into play in the SEA equations.

The dissipation in an acoustic cavity is usually defined in terms of absorption coefficient $\alpha$ (or absorption area). For a closed cavity $i$ with a total surface $S_i$, the absorption area is $\alpha S_i$. From the SEA point of view, the dissipation is represented by a damping loss factor (DLF). The power dissipated in a cavity $i$ is given by the absorption area and the intensity $I$ by $P_{\text{diss},i} = \alpha S_i I$.

Then, the DLF is

$$\eta_i = \frac{S_i c_0}{4 \omega V_i} \alpha$$  \hspace{1cm} (2)

where $c_0$ is the speed of sound and $V_i$ the volume of cavity $i$.

Let us consider two cavities separated by a panel. The incident wave from cavity $i$ is transmitted via the panel of surface $S_p$ to cavity $j$. The wave attenuation is characterized by the diffuse transmission coefficient $\tau_d$.

Then, the coupling loss factor (CLF) between $i$ and $j$ is

$$\eta_{ij} = \frac{S_p c_0}{4 \omega V_i} \tau_d$$  \hspace{1cm} (3)

In the case of a simple two cavities system, the energy in cavity $j$ is deduced from the power balance equation,
where $p_{exc}$ is the power in cavity $i$ and $\rho_0$ the air density. It is worth emphasizing how the absorption and transmission coefficients are distributed in the SEA equations (2) and (3) and how they characterize the energy of a receiving cavity. From equation (4) it is observed that the reduction of energy in cavity $j$ can be obtained either by a transmission coefficient $\tau_d$ diminution or by an absorption coefficient $\alpha_j$ augmentation.

### 3.2 Simulation of transmission loss and absorption

Each panel of the topological model must have a TL and an absorption curve. These data are crucial in the usage of the SEA model and must then be carefully defined. Indeed they are decisive for the model reliability on one hand, and for the panel contribution analysis on the other hand. These points are deeper discussed in the next section.

The evaluation of TL and absorption is not straightforward especially for complex components such as the dash and the floor. The trim part usually does not cover all areas, it may have a variable thickness; may overlap with other parts; have a non-homogenous construction (a variable bill of material, so-called BoM) can be used and accessories may be present on the panel. As a hint, Bertolini [3] proposed a procedure that separates the panel areas in three subdivisions: (S1) the uncovered areas, (S2) the areas with accessories and (S3) the area covered by the acoustic trim. Moreover, a single component part, such as a dash insulator, may cover several SEA panels and therefore may be split into sub-areas. In the end the global TL and absorption of the part is simply the area-weighted average of the transmission and absorption coefficients of all sub-areas.

For complex parts (floor, dash, trunk sides, etc), the simulation of the acoustic trim is carried out by means of the Transfer Matrix Method (TMM). This thickness based 2D method assumes that each layer from the bill of materials is homogeneous, isotropic and is an infinite medium. Various types of waves can propagate in a layer depending on its nature. As it is based on 2D analysis, TMM cannot take into account neither the detailed shape of the acoustic treatment nor its interaction with the structure. Nonetheless, at the same time, trends are well represented and very good computation efficiency is guaranteed compared to methods based on Poro-Elastic FE.

In practice, starting from the CAD surfaces of the trim part, the A and B surfaces are extracted and thickness map is computed from the distance the two surfaces. Having the equivalent 2D multilayer that corresponds to the complex decoupler, one is able to add the other layers of the BoM (cf. Figure 4). Several TMM-based software packages are available on the market: NOVA, AlphaCell, Foam-HF (VAOne), etc. Internally, Autoneum has its own software: Visualsisab [W1]. The main advantage of Visualsisab compared to other TMM-based software solutions resides in its high versatility for assessing any design change, as it integrates the part geometry (thickness distribution), the layup construction (even when the construction is inhomogeneous) and thickness-dependent material modeling.

![Figure 4](image-url)

There are many possible outputs from the TMM, TL and absorption are part of them. Each layer of the BoM is supposed to be known. For fluids and structural layers, usually the knowledge of thickness and density is enough to assess the performances. That is not the case for porous materials where Biot
parameters are needed. These can be recovered from a material database or directly measured from a part. In the next section the Autoneum tools to provide such data or even directly the TL and absorption are presented.

To sum up, parts that have a CAD acoustic trim are simulated with the TMM from the physical properties of their BoM. For the seats, typical TL values are carried over. Absorption coefficients are measured or taken from a database. TL of the other panels are calculated using a mass law.

3.3 Autoneum measurement systems

3.2.1 ELWIS

The “Evaluation of Light Weight Impedance System” (ELWIS) [W2] is an Autoneum measurement tool that provides the acoustic and structural parameters of a porous material. For a given sample, on one hand, ELWIS-S, the structural measurement tool, gives the density, the Young modulus, the loss factor and the Poisson ratio. On the other hand, ELWIS-A, the acoustic part of the tool, gives the AFR, the tortuosity, the viscous and thermal lengths, the shape factor, the absorption and the impedance.

From these measurements and notably the Biot’s parameters one is able to simulate the porous material using the TMM. Results from the simulation are generally pretty well correlated with measurements.

3.2.2 Alpha cabin and Isokell

The Alpha Cabin [W3] is a small reverberation room. It has been designed so that the sample size is adapted to the requirements of automotive acoustics. The output is an absorption curve on the frequency range 400-10000 Hz. Usually parts where there is no need for the complete Biot parameters are measured by such a system (for example: parcel shelf, headliner).

The Isokell [W4] system is simply an alpha cabin coupled to an excitation chamber. It provides the transmission loss curve of a part on the frequency range 125-10000 Hz. Figure 5 illustrates ELWIS and the alpha cabin measurement systems.

Figure 5 – Left hand side: The ELWIS measurement system; Right hand side. An Alpha-cabin.

Figure 6 – (Left hand side & center) Masking of the air intake and a cable PT of the Dash. (Right hand side) Masking the air evacuation hole of a trunk panel.
4. VALIDATION AND EXPLOITATION OF THE SEA MODEL

4.1 Taking into consideration flanking paths and leakages

In the previous section we discussed the evaluation of a part’s performances where a “part” was implicitly an area covered by the body in white and the trim. A question can then be raised: how holes (flanking paths) and more generally leakages are taken into account in the SEA model? Indeed this interrogation is important for parts like the dash, the doors, the fenders, the trunk, etc.

In our SEA model, a leakage is represented by a TL. The TL can be estimated directly on the car with an in-situ masking process: all pass-throughs (PT) are masked by a high TL material (denoted as MAX package) and the SPL of the passenger compartment cavities are measured. Then the masks are removed PT by PT and the SPL are again evaluated. The difference between two SPL - with and without MAX package – can be used to define the TL of the pass-throughs in the SEA model. Such an approach is easy to interpret. Nevertheless it can be very long to be put in place. And this is true especially for the Dash where PTs are difficult to reach due to the instrumentation panel. If these data are not available (for time consideration or anything else), there is still the possibility to represent the PTs with a low TL (compare to the TL of the corresponding panel) and to tune it up afterwards, during the model validation.

Several pass-throughs can be part of a panel and they will reduce the ‘effective’ area. Then, the transmission coefficient of a component (the part plus its PTs) is calculated as follows

\[
\tau_{\text{total}} = \frac{1}{S_{\text{panel}}} \left[ \left( S_{\text{panel}} - \sum_k S_k \right) \cdot \tau_{\text{panel}} + \sum_k S_k \cdot \tau_k \right]
\]

where \( S_k \) and \( \tau_k \) are respectively the surface and the transmission coefficient of pass-through \( k \).

Figure 7 compares the sensitivity of a PT after tuning its TL. To do so the TL is fixed and progressively reduced so that the simulated sensitivity in red agrees with the one from measurement in blue. Ideally this sensitivity analysis must be done for all excitations but it’s common to do this check only with the closest excitations. For the dash PT for instance, the analysis can be limited to the engine bay and the front tires excitations.

Figure 7 – Sensitivity analysis after tuning the TL of a PT. SPL difference from measurements in Blue, from simulation in Red.

Figure 8 – Validation based on Acoustic transfer functions
In the same way, one can check the sensitivity of a complete panel. It can be very helpful to check the TL obtained from the TMM simulation. Nonetheless, to do so MAX packages must be applied on the surrounding panels and this is time consuming.

4.2 The SEA model validation

Once that TL and absorption data are defined for all panels, that pass-throughs performances are checked and all loads measured, the last part consists in validating the model. It is the direct comparison between two SPLs: the one obtained from the SEA simulations and the one from measurements.

The measurements of the acoustic transfer functions (ATF) at the ears position have to be reproduced by our SEA model. Such a transfer function is the measured pressure $p_m$ at the driver’s ears normalized to the excitation strength $Q_i$. The loads measurements provided the external excitation for all external panels $j$ and SEA simulation gives the pressure $p_{SEA}$ of the passenger compartment with respect to the loads. Then,

$$\frac{p_m}{\sum Q_i} = \frac{p_{SEA}}{\sum Q_i}$$

(6)

Figure 8 illustrates the process described by equation (5). Figure 9 gives an example of results for a B segment car. Here the excitations are located in the engine bay and the SPLs are compared at the rear cavities (rear passenger’s ears). One observes a pretty good correlation between SEA and measurements meaning that the TL, absorptions and loads database represents well the physics.

Figure 9 – Comparison between measurements and SEA simulation. Driver side (DS) and passenger side (PS) are distinguished.
4.3 Contribution analysis

The aim of a contribution analysis consists in evaluating the sound pressure level (SPL) contribution of a specific panel at a receiver microphone, usually placed at the driver head. Thus, contribution analysis is intended to be used for diagnostic purposes. And as often, after a diagnosis comes an action: the prediction of how such a contribution changes when a specified acoustic treatment is applied is the logical next step.

There are few experimental techniques to address panel contribution. Among them, the masking technique is quite widespread. Here there are two ways to proceed: either the contribution of a panel is measured directly by artificially reducing as much as possible the acoustic radiation from the others, or the mask is applied alternatively on each panel whose contribution is to be obtained. Either way, masking is the usage of MAX packages and the advantages and drawbacks have already been mentioned: even being a pragmatic and intuitive method, it is time consuming. In addition, in real automotive cases, the presence of several MAX packages may influence the dynamics of the structure and the acoustics of the cavity.

Figure 10 shows some results from a cumulative panel contribution analysis. Here, the masking technique has been used at a virtual level. In the simulation, the masking of a panel (or a group of panels) has been done by switching off its imposed SPL. In this way, only the other panels are likely to contribute to the SPL of the passenger compartment. Figure 10 displays the contribution of five groups to the SPL at the driver’s ear for engine bay excitation. As it has to be expected, the most important contributions come from the dash and its PTs while less relevant contributions comes from the floor and the sides. If one wants to reduce the SPL in the driver ears cavity it is then natural to “work” on the most contributive panel, the inner dash in this case. Now two interrogations come: what shall we do to reduce this SPL? Shall we improve the TL of the panel or its absorption?

5. TARGET CASCADING ANALYSIS

5.1 Main aim

The target cascading analysis is an optimization procedure based on the panel contribution analysis. The PCA allows having access to a prioritization of the information, a classification of the contributions. This information is linked to the panels and cavities features, the transmission and absorption coefficients. The aim of TCA is, for a quantified SPL target reduction, to find the optimal solution in terms of TL/absorption targets database that will reach this objective. In order words, it translates a SPL requirement into components requirement with the minimum TL and absorption effort. In a project, after the validation of a baseline SEA model (a database composed of TL and absorption) by correlating the simulation with the measurements, the OEM defines target SPL for several cavities.

Figure 10 – Panel contribution analysis for engine bay excitation for a B-segment car

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<th>Frequency (Hz)</th>
<th>Contribution (%)</th>
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Figure 10 – Panel contribution analysis for engine bay excitation for a B-segment car
(typically, driver and rear passenger cavities). Directly depending on the results from PCA, the TL and the absorption are numerically modified until the SPL target is achieved.

The main difficulty in the TCA implementation is that TL and absorption are two features that are simply not comparable. The first one is measured in dB (like the SPL) and is part of the coupling loss factor (i.e. the junction canals in the water tank representation). At the opposite, absorption is not a logarithmic value. It is linked to the panel but contributes to the total energy dissipation of the cavity. Improving the absorption by 0.1 does not necessarily trigger a SPL reduction by this amount. A way to avoid this question is to use instead the absorption loss, AL, defined by \( AL = 10\log(-\ln(1-\alpha)) \).

The first step of TCA is the sensitivity analysis. It is the derivative of the objective function, the target SPL, with respect to the design variables, TL and AL. Then, the design variables are incrementally updated according to the derivative obtained in the previous step. Finally the SPL of the target cavity in the updated configuration just obtained is re-calculated. This three-steps process is repeated, for each frequency of the bandwidth of interest, until the target is achieved. Paper [4] gives the detailed procedure plus an application on a complete vehicle.

5.2 Handling single and multi-targets

For a single target, the TCA method does not bring particular questions: a single SPL curve is defined for a cavity and a source. For example, the required SPL at the driver’s ears cavity is -3dB lower than the baseline SPL, for all frequencies and for engine bay excitation. Then, after applying TCA, one shall have an updated database of TLs and absorptions so that the new SPL agrees with the target. It wouldn’t be a surprise to see improvements in terms of TL and absorption focused on the dash part because it is composed of the most contributive panels.

For multi-target, the TCA procedure is not any more straightforward. For example, three targets are defined: one is concerned with driver cavity/engine bay excitation, one is for driver cavity/front tires excitation, one is for rear passenger cavity/rear tires excitation. Taking each target independently and merging the three obtained databases into one has been considered. Nevertheless, such a process gives a new SPL far lower than the SPL target meaning that the database is over-engineered. A second way to operate is taking the three targets one after another, starting with the most demanding one. In that case one ends up with three SPLs closer to their targets. Of course the final database is still over-engineered but less than for the parallel procedure. In the end it is still an open point and the question is: do we really want to achieve absolutely the targets or are we ready to propose a compromise where the target are almost achieved for all cases? In the case of such a compromise, then one shall think about a sensitivity analysis, preliminary step to TCA.

Figure 11 illustrates the two approaches. Here several targets have been defined but results are displayed just for one, rear passenger cavity/rear tires excitation. The blue curves represent the baselines; the red curves the targets and the green curve the ATF after TCA. On the left hand side, a linear procedure has been used. The target is reached and is even overachieved due to the fact that the database has been ‘reworked’ for the other targets. On the right hand side all targets have been considered at the same time and a gradient-based method has been used for optimization. One observes that the target is not fully reached; there are discrepancies of few dB between the red and the green curve. A compromise has been found; the final database does not fulfill perfectly the requirements but tries to get closer to them avoiding any over engineering.

![Figure 11](https://example.com/figure11.png)

**Figure 11** – (left hand side) a linear TCA, (right hand side) with a gradient-based optimization
6. CONCLUSION

This paper shows how an SEA model has to be practically tackled for the sake of efficient air-borne acoustic improvement of a car. Given the complexity of the variables and quantities to be taken into account for a complete representation of a vehicle NVH, this paper shows that it is possible to make a compromise and concentrate on the most relevant aspects that influence the decisions that drive the air-borne improvement. Some hypothesis or simplifications are done, such as the tuning of pass-throughs performance based on in-situ measurements, or the neglecting of structural SEA sub-system. Those are only examples.

However, it is known that this level of representation is sufficient for the application of optimization procedures for the prioritization and quantification of component targets, given a global vehicle target. Indeed, this paper was concerned with the translation of a global SPL targets into parts targets. For that the panel contribution analysis and the target cascading analysis have been presented in the framework of an SEA model.

Finally, we can conclude with considerations about the exploitation of the component targets. It is known that OEMs specify most of acoustic targets at part level. As a consequence, the result of the TCA allow the OEMs and suppliers to relate the fulfillment of part acoustic objectives, such as TLs, to an overall vehicle target, such as SPL or ATF at driver ear position. Additionally, and thanks to the development of software such as VisualSISAB based on the TMM, the definition of component targets can be exploited for the optimization of a cost, weigh and performance effective part design. At the end of an SEA project collaboration, gathering OEMs vehicle information and targets, together with design capabilities of part suppliers, it is practically possible to rationalize a vehicle level target into decision making in terms of materials, part thickness and geometrical changes.

REFERENCES


WEBLINKS