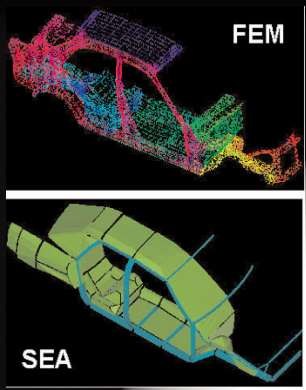

Prediction of Cabin Noise inside passenger cars: the Airborne Noise Project

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Statistical Energy Analisys Introduction

This short preview is a presentation of the basic theory and procedures for application of a branch of study of systems dynamic called Statistical Energy Analysis (SEA) in NVH applications.

The name SEA coined in the early 1960's emphasises that the systems being studied are presumed to be drawn from a statistical population of modes having known distributions of their dynamical parameters.

The technique takes care of the Energy as the primary variable of interest, while the others dynamical variables such as displacement, pressure, etc., are derived from the energy.

Traditional analysis of mechanical system vibration of machines and structures have been directed at the lower few resonant modes (FEM, BEM) for their greatest displacement response and excitation. This approach is concentrated in the so-called "Low Frequency range" (0-200 Hz) and not in "High Frequency Range" (from 200 Hz on ...) due to the cost of the implementation of models based on enormous quantity of data, consequently size and resolving time increment.

Due to the long time developing and calculation in the FEM and BEM methods in the HF range a different approach was implemented based on the increasing number of modes avoiding the direct knowledge of the single modes but having a statistical management of them.

This idea deals with the room acoustics where due to the presence of the many degree of freedoms (there may be over a million modes of oscillation in the audible frequency range) is impossible to understand without considering a statistical approach.

In this state of vibration, all modes, whether they resonate at frequencies near each other or far apart, tend to have equal energy of vibration and to have incoherent motion; on the other hand many of the system we may wish to apply SEA may not have enough modes in certain frequency bands to allow predictions with an acceptable degree of certainty.

For this reasons Statistical Energy Analysis is a recent method apply to the automotive industry where the subsystem some times doesn't have the required minimum numbers of modes; for this reasons the SEA method is not in conflict with the previous technique FEM and BEM but is applied in a different field of the spectrum. The future idea is to combine the three methods to have a complete simulation of the all range of frequency.

The application of the method in automotive field is relatively recent, we can find one of the first application in the middle of the 80's but from that period many effort are made and the literature is widely spreading in all the NVH applications.

The interest in the high frequency range, more dealing with the human hearing (the maximum audibility is around the 4KHz), in the automotive application is concentrated in the efficiency of the habitability of the cabin. In particular the part of the spectrum that goes from about 300 Hz to 10 kHz is strongly dominated and influenced by the sound package's efficiency.

The present research in this field of application has the aim to define the target achievements to propose to an automaker a sound package able to reach the targets set and/or in a second moment to evaluate the cabin sound pleasantness. The target and the levels reached are important to have some analytically methods that can help automaker and the suppliers to define the quality of the car and the possible improvements and removal of weakness of the car.

The procedure step followed till now is to define target on P/P transfer function without having a percentage of the weight of the different sources and absorption in the passenger compartment.

The SEA approach is able to define the right contributes deriving from weakness of the sound package oblige, on one hand, the suppliers to improve their materials, on the other hand, defining the percentage of the leaks and flanking paths due to the weakness of the structure itself out of the supplier's task. This application defined in each particular could be one of the request for the proposal of the study of a new car, defining target, efficiencies component in the different part of the car.

Goal of the Airborne

The Airborne Noise Project is a new methodology proposed to automaker to define one possible technique for setting the sound packages target and related the cost/benefit for new cars for future improvements.
The initial goal is the definition of the possibility to simulate the P/P transfer function for different sources.

This method will be useful at the end of the project to define weight of different packages, targets and possible inefficiencies of others particular in the car (leaks, flanking paths).

The combination of different targets like leaks, sound isolation, absorption, flanking paths and their weight in the passenger compartment can be the starting point to define possible improvements in the quality of the car.

Method approach details

The new methodology developed is related to the geometry of the car, the materials composition, the validation with measurements.

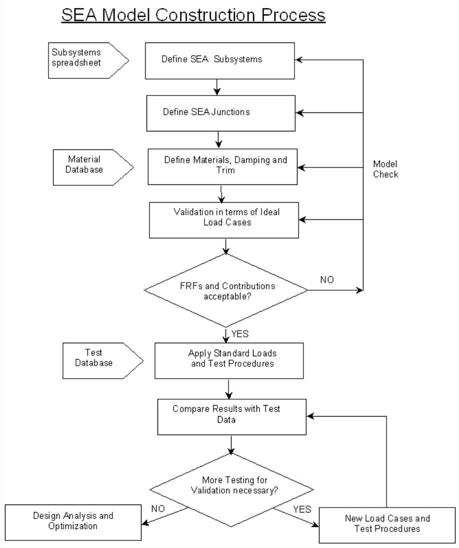
To have a solid measure and materials properties database, for Airborne Noise Project, was decided to developed the model on a car that was already on the market (ALFA 156) and concentrate the effort in studying the P/P transfer function (Pressure to Pressure ratio), that are mainly derived from the main three sources: engine, muffler, tail tube. Related to the three sources there are three main isolation to study:
1. the dash related to the engine emission
2. the floor related to the muffler emission
3. the tail tube connected to the study of the rear part of the car

To achieve the isolation spectrum the settlement for the three different measure are as follow:
1. Dash: measurements are related to the Sound Pressure Level in the engine compartment related to the passenger one where the microphones follows the points in Fiat position rules 7 R3000. (microphones position see appendix B)
2. Muffler: the defined source is positioned under the front floor and the microphones measure the sound radiated by the source, while the internal position are the same of the dash measure.
3. Tail Tube: the tail tube of the car is substituted by a defined ruled source measuring its emission while the internal microphones are positioned following the Fiat 7 R3000 standard.

The three main parts of the model were assigned to the three partners of the project.
The method followed by the three partners in a model development is presented in the iterative process that describes which is the main step.

Steps used in the model preparation:

Geometrical data acquisition: the data can be measured on one prototype or on CAD geometry.
Materials database acquisition: the materials data can be acquired from one old database or introduced in the model with the physical properties.
Developing the first SEA model
Measuring the P/P transfer function
Verifying the model by P/P measurement
Validation of the model: to understand the accuracy of the model the validation is made by changing some parameters on the car and in the model to check if the variation is followed in the right way.
Delivery of the model
Possible improvements: implementation of new materials, changes in sound packages weight or geometry.



Airborne SEA Model for the Tail tube problem

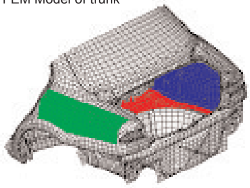
The model was build with the software AutoSEA version 1.5.7 developed by Vasci and the first step to build a SEA model is to define the system in the real car that will be simulated with an equivalent subsystem.

In many cases the AutoSEA subsystem is a simple representation of a flat or cylindrical panel or in the case of a cavity a cube. This kind of representation doesn't match the real component that has halls, ribbed beams and a shape that are different from the flat ones. In this view seam that the SEA model is far from what is the reality, but what is important to understand and simulate is the real number of modes that bring the energy in the subsystem; in this way of thinking the problem is to built one equivalent element that have the same number of modes.

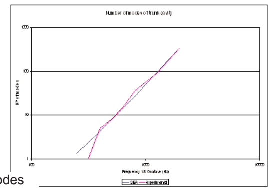
For example the cavity of the trunk is a simple cubic hollow which characteristics are the volume, the total area, the perimeter and the internal absorption.

In the first graph are reported the numbers of modes calculated with the SEA model and measured in the trunk compartment; in this first graph is possible to see that the equivalent cavity matches the real one.
To obtain equivalent subsystems that form the SEA model we started dividing the car geometry in four hypothetical parts: the external, the trunk, the labyrinth connection between the trunk and the passenger cavity and the passenger cavity itself. The measure of the geometry and external sound energy were made on a car prototype.

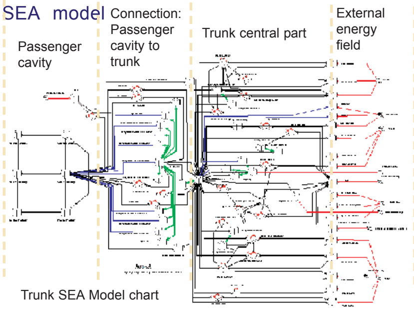
FEM Model of trunk



As it can be seen, the SEA model



Trunk acoustic modes



Trunk SEA Model chart

is a mixture of subsystem cavities, panels and connections as indicated in a very schematically way for the interpretation of the model. In this way the model of the rear part of the car doesn't look a car but a mixture of hydraulic like network with cavities, panels and connections.

The solving speed of an SEA model is really "fast" compared to more traditional FEM or BEM methods and it gives the possibility, once validated, to run several times the calculus upon changes of different physical parameter and obtain different condition in testing sound packages.

The exterior part

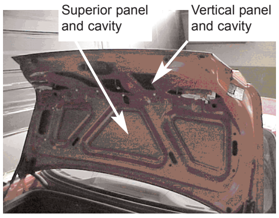
To have a good representation of the distribution of the sound around the car there were built an array of microphones all around the rear part; the exterior part is divided in 23 cavities simulated with the same number of SEA subsystem representing the exterior distribution. In each cavity was inserted the average energy derived from sound pressure measurements SPL and converted in energy. The source was the tail tube plus one extra microphone as reference.

The external part of the car in the SEA model represents the field distribution all around the rear part of the car in terms of energy distribution. The rear door are not measured and this is a limitation in the transfer function from the rear part to the internal passenger cavity.

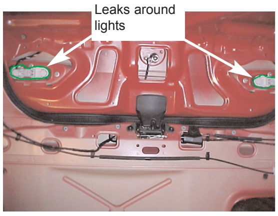
The trunk

Trunk is build using 12 flat panels, 4 cylindrical panels and 6 cavities: spare tyre place, two internal in the trunk lid, two between the quarter panel and the shock towers and the main cavity. The sound package itself constitutes the cavities limits inside the trunk.

The Trunk Lid

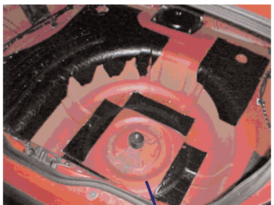


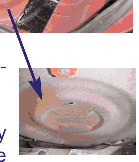
The trunk lid was divided in two parts, the superior and the vertical one. The trunk lid is covered by an absorption material URS (recycled foam) and TNT that define the cavity present in the structure of the lid. In the trunk lid are also present three important leaks, two related to the lights and one due to the seal of the lid itself.



Spare tire tube

Spare tire tube cavity is separated from the main cavity by the heavy floor carpet that covers almost the trunk floor. Drain hall leak doesn't influence the measure in the trunk compartment due to the heavy carpet that close completely the cavity. In the first model this hall was included but removed in the last revision.





The volume of tyre is subtracted by the total one; the reason it's due to the fact that the real volume set the total number of modes in the cavity; on the other hand the mass of the tyre doesn't perturb the modes of the panel. The mass is concentrated in a few points of the panel considered as blocked ones that doesn't affect the total number of modes, in fact in the SEA way of thinking the blocked points in a panel are not influencing the near ones and in consequence the total modes number.

The Exhaust air system.

One of the most important part to simulate in the model was the Exhaust air open in the trunk cavity on passenger side.
This aperture, made for exchange of air with the outside, is one of the most source in the trunk compartment.
As reported in the picture it is covered by two lips of plastic material whose weight are 1.9 and 2.4 gr. This source was take in the model as the primary source and so evaluated in different ways as reported below.

In the first model this two leaks, 22 and 24 cm respectively, were simulated like slit; while in the second model was implemented the solution to represent the system without leaks but inserting the real mass of the lips (1,9 and 2,4 grams) plus the overture of the sound package taking in to account the weakness of the lips that makes the cover.

The problem related to this part of the car, or similar path, is not really concerning only with the leaks or weakness but a mixture of them. One idea, for future model, could be to take into account the possibility to introduce one "Transmission Loss" that is the combination of the leaks and weakness of all the part.

This part was studied by different solution covering the system with heavy mass and measuring the SPL in the internal and external part; this measures were utilised for understanding the changes in the model.
In the opposite side of the trunk there is another weakness, relieved during the study of the trunk, a plastic plug that covers one area of 8 x 12 cm. All this part are not directly connected to the central cavity but are covered by absorption material URS (recycled foam).

Rear shelf

The connection between the trunk and the internal cavity of the car is one another important part of the model. This part is a very complicated structure made of one central cavity formed by the rear shelf and the under shelf cover (the central picture reported below) and by the presence of 11 halls plus the C pillars.

In the upper part of the shelf there are 7 halls (20 x 2 cm the central one; 12 x 2 cm the lateral ones; 10 x 2 cm (n° 2); 8 x 2 cm (n° 2)) for the exchange of air between the passenger and the trunk cavity.

The path of air goes from the main cavity to the under shelf one, reported in the picture n° 2. In this picture is not present the absorption materials (porous felt). The cavity has other four important connection from the passenger cavity: the two loudspeakers and the seat belt halls. The loudspeakers place, in the central part of the shelf picture, are cover by a felt material, transparent to the sound, the loudspeakers membrane due to their way of functioning are transparent too. For this kind of reason there are two halls 20 x 20 cm that connected the passenger compartment directly to the under shelf cavity.

Looking the shelf from the trunk side the under rear shelf has two halls in the central part near the seat.
The model of this part takes care not only the pass through of air but also the weakness of the structure that comes out from some measure: the C pillar.
On the sides of the rear part of the internal cavity there are the C pillar connections. In the C pillars are present two cavity that are connected directly to the trunk and have one hall in the passenger side. (C-pillar 3)

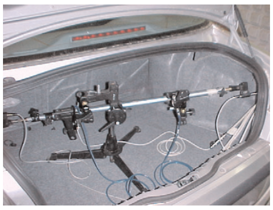
The trunk cavity

The SEA main model subsystem is the trunk hollow reported below. The walls are covered by URS material on the two lateral sites and on the rear seat, while the carpet and the under shelf cover are composition of mass and porous stuff.

The most important physical parameter to inset was the absorption of the cavity. In the AutoSEA software is possible to have two different approach: theoretical and experimental.

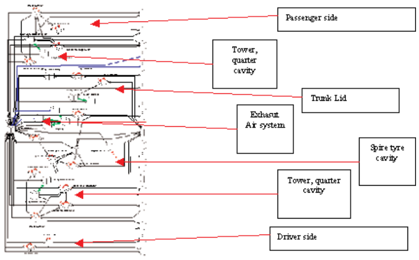
The theoretical way needs to insert the physical parameters of the stuff that form the cover of the cavity: flow resistance, thickens, density and so on; this is not sufficient because it is necessary to insert also the gaps of air that there are between the material and the panel. It is difficult to obtain this measure due to the fact that the gap of air between the different material is not constant and it has a big band of variance (from about 1 mm to 10 cm). This difficult was avoided by measuring the total absorption of the cavity by measuring the time reverberation decay, from which is possible to derive the needed data.

This kind of measure takes care also of the absorption of the rear seat that are present in the wall that divide the passenger cavity from the trunk one. In fact this part is divided by a steel panel but it has a lot of halls where the seat are directly in contact to the trunk cavity increasing absorption



The trunk SEA modeling

The panels (flat or cylindrical) represent all the others part of the car while the absorption is obtained by measurement of T60 in the main cavity (appendix). In this part of the model is present also 5 important leaks, two related the air exhaust system, two by the seal around the lights and one around the trunk lid seal. Furthermore there are some weakness of the structure (example the plastic plug on the internal quarter panel in the driver side).



Trunk SEA Model details chart

The upper part is the passenger side of the car while the bottom the driver's one. In the central part is possible to recognised the spare tire tube cavity, the floor and the leaks of the air exhaust system.

The internal cavity

The internal cavity was developed by another partner (CRF) while the connection with the trunk was a jont task. This connection part is rather complicated due to the acoustical labyrinth of the rear shelf. This part is simulated in three cavity (one as the under rear shelf and two internal C pillar cavities), 4 panels and leaks that represent the connection of the loudspeakers, i.e. the halls in the rear shelf.

In the cavity under rear shelf there are present some absorption materials simulated with the introduction of the materials physical properties.

The passenger cavity is divided in six part and it is possible to recognised the introduction of energy in the rear part of the glass. In the representation of the results is possible to recognise the coincident frequency of the rear glass at about 4HKz.

Experimental validations

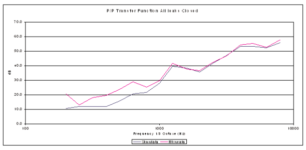
The model was validated in different way by measuring the acoustical TF (Transfer Function) from the exterior to the trunk and to passenger cavity applying different conditions. Another validation is given by the modal count of three main panel (trunk floor, quarter panel, rear panel).

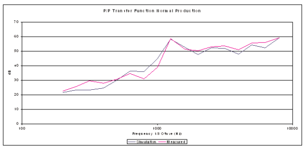
The acoustical validations are based on the concept that the model changes should fit one variation on the car. This way of working tells if the model is able to follow different settings, representing the different conditions of the car.

The settings considered are the following:

1. Normal production
2. Exhaust air open; seal around the lid were closed, lights leaks were closed, hall of spire tyre tube closed
3. Seal around the lid open, exhaust air closed, lights leaks were closed, hall of spire tyre tube closed
4. Seal around the lights open, exhaust air closed, seal lid closed, hall of spire tyre tube closed
5. Hall spire tyre tube open, exhaust air closed, seal lid closed, seal around the lights open
6. Exhaust air closed; seal around the lid were closed, lights leaks were closed, hall of spire tyre tube closed

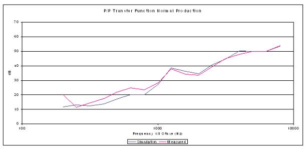
The first model validated was the one called "All leaks closed", in this model it has been tested the maximum P/P ratio due to the structure of the car excluding some variables like leaks and weakness of the structure.


Graph of the transfer function between the exterior part and the interior of the trunk compartment

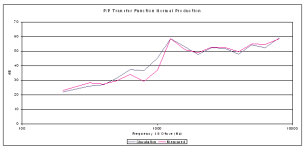

Graph of the transfer function between the exterior part and the interior of the passenger compartment

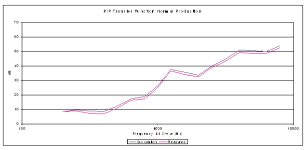
The validation are P/P for the trunk and for the interior of car, in this kind of graph the solution is related to the doors and the roof that is the model developed by another partner (CRF). In this graph the variation is limited by the injection of energy due to the presence of the rear glass and the lateral ones.

The second settings tested was the Normal Production simulated with a total model.

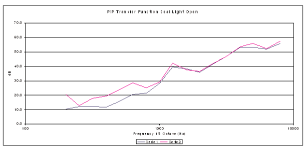

Graph of the transfer function between the exterior part and the interior of the trunk compartment

Further steps were the opening of one or more halls to see the effects. The most important is the exhaust air opening that is situated in the right side. The hall to simulate has two different path one dominated by the mass and one by the leaks.


Graph of the transfer function between the exterior part and the interior of the passenger compartment


In the graph are represented the simulation of the P/P transfer function on Alfa 156 and a possible increment of the P/P ratio due to improvement in the car.

The exhaust air system is composed by two lips of only few grams (about 6 due to the composition of the absorbing materials and the weight of the lips) and by the presence of two long leaks about 24 centimetres.


Graph of the transfer function between the exterior part and the interior of the passenger compartment.

Another setting tested was the simulation of the leaks due to the seal of one light.

In the trunk compartment the seal that closes the perimeters of the lights has some weakness represented in the model like a leaks simulated with the slit behaviour.

In the measure that are reported in this relation the source used was the tail tube simulation ruled by Fiat but this source hasn't the power to excite with a sufficient power all the subsystem of the car. So in the transfer function from the exterior to the interior there are some flanking path due to the presence of the glasses. For the rear one is possible to see the effect in the model not for the others due to the lack of measured data.

For this reason the simulation of the P/P from the external to the internal of the passenger side doesn't show an appreciable gap between the measurements.

Improvement of the model

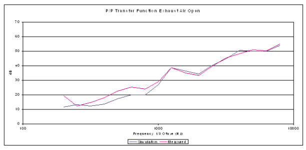
As reported in the previous paragraph the increment in the P/P of the passenger side for the rear part is due to the presence of the rear glasses, limiting the changing in the model.

In fact as possible to see in the injected power graph from 1.6 KHz all the energy is given by the rear glass by a resonant and non resonant law.

Whit this graph is possible to understand way changing the setting of the car the P/P ratio from 1600 Hz to 8000 kHz doesn't change, or better the ratio is under the uncertainty of the measure itself. The possibility to measure the P/P ratio under other condition could be the better way to understand the transfer paths in the rear part of the car.

In the part of the spectrum where there are others sources is possible to recognise that the halls on the rear shelf have some influence, but they are quite few in comparison to the size and the number of halls. For the transfer function of the trunk cavity the P/P ratio can be modified due to the presence of many variable sources.

One of them take in to consideration during the model development is the exhaust air system. This part has two weak point one due to the light mass of the lips and the second to the presence two long slits. Reducing the slit from 24 cm to 12 and adding 10 grams for each lips the simulation gives us the result reported in the graph below. It is possible to see that the two improvements one in the low frequency, the mass, and the second in the high range give a better solution from 1 dB to 2.5 dB in almost all the spectrum.


Graph of the transfer function between the exterior part and the interior of the trunk compartment

Appendix: Measurements on Alfa 156

Measurements on Alfa 156 were divided in three different kind: P/P transfer function, Time reverberation delay, Modes count

P/P transfer function: SEA modelling of rear part of the car - The external measure

To evaluate the SEA model of the rear part of the car some measures were peromed according to Fiat rule 7 R-2200, spread in more points to follow the SEA way of measuring. This is an important point to be discussed.

The sound field that is facing on a panel has not a constant level and the measure of the SPL changes

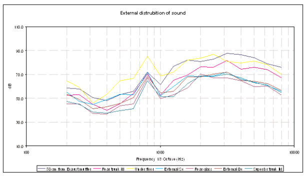
with microphone positions, in other words, the position influence the P/P ratio and insulation values. The P/P ratio has to be considered as the levels difference between two microphones. It is obvious that internally and externally, the distribution of the sound is not constant, even in one SEA single subsystem. To have an average distribution of the sound, the SPL is sampled in more places and the average applied to the subsystems.
Anyway, SEA levels are "average levels" derived from the energy of all regions defined as subsystem in the model. For this reason, SEA's measures assume that in a region the energy is constant, it is clear that the distribution of the sound around the car and internally must be taken in mind in some way.

For measurements, one microphone was taken as reference (near the exhaust tube at 50 cm), other microphones around the rear part of the car, following the subdivision that were decided in the SEA model. In this assumption the external part was divided into 22 SEA cavities. For each cavity were made averages of different random positions, in some cases, few microphones for the difficult of the position to reach (for example the cavity between the exhaust opening and the bumper) in other ones many more positions.

The measures, reported in the graph, were introduced in the model as sources.

Yellow	Under trunk floor
Blue	Reference microphone at 50 cm from the exhaust muffler
Pink	Rear trunk lid
Light blue	Quarter panel driver side
Brown	Quarter panel passenger side
Sea green	Superior trunk lid
Violet	Rear glass

It is possible to see that sound shows picks at 630-800 Hz, due to the sources, and that all sources have one trend accept the under trunk floor; this measure is influenced by the floor of the car and show a different trend, in the low frequency is the most powerful, while in the high range follow the reference microphone.


External distribution of the sound around the ALFA 156. Different lines represent SEA subsystems as reported in the legend

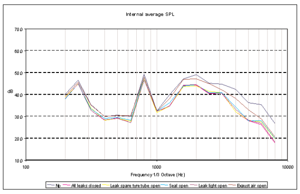
The internal cavity

The internal cavity of the trunk was sampled with 5 microphones moved in different positions defined for understanding some behaviour in the car. The tests that were performed are a combination of the settings described in the following list:

1. Normal production
2. Cover of the exhaust air opening with mass
3. Cover of seal in the trunk lid with mass
4. Cover of leaks around the lights with mass
5. Cover of leak in the spire tyre cavity
6. Closure of the loudspeakers
7. closure of halls in the rear shelf

Some combination didn't bring an appreciable gap that can be evaluated so are not reported in this relation. This different solution was decided to understand the contribution of the exhaust air opening, the leakage of the lights, leakage of the seal etc.
The operating settings that we followed were to measure the car in the Normal Production and to compare the results with other obtained covering all the possible halls that were evaluated as important in the trunk P/P transfer function.
In the graph are reported the SPL average measured in the trunk cavity with different setting described below.

Red	Normal production
Violet	Exhaust air open; seal around the lid were closed, lights leaks were closed, hall of spire tyre tube closed
Light green	Seal around the lid open, exhaust air closed, lights leaks were closed, hall of spire tyre tube closed
Sea-green	Seal around the lights open, exhaust air closed, seal lid closed, spare tyre hall tube closed
Blue	Hall spire tyre tube open, exhaust air closed, seal lid closed, seal around the lights openings
Black	Exhaust air closed; seal around the lid were closed, lights leaks were closed, hall of spire tyre tube closed


Graph of P/P external/internal trunk cavity
Lines represent different solutions

It is possible to see that closing the exhaust air opening the level decrease by 4-5 dB around 3KHz to 10-12 at 8KHz.
On the other hands, others solution (closing the leaks around the lights, fixing the seal and closing the spire tyre tube leak) are quite the same.
From the SPL measure inside the cavity and that ones measured externally it is possible to calculate the P/P ratio.
In the graph is also possible to see a shape due to the mass law (250 - 630 Hz), two weaknesses: between 800-1000 Hz and 1250- 1600 Hz.

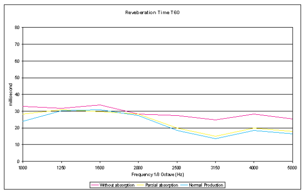
Reverberation Time measurement

To measure the reverberation time we try two different sources: a loudspeaker connected to the car and a balloon in the trunk compartment. The first solution was not good enough, in fact after the measure was clear that we were measuring the time decay of the membrane of the loudspeaker. The ballon blasting instead was used in the trunk.
A baloon was inserted in the trunk near to the light of the passenger side substituted with a heavy mass plug were was possible to insert one needle. The explosion was recorded on a DAT cassette and after filtered in 1/3 octave band and analysed.
The data collected were divided in three different sets of measurement:

1. Normal production (passenger and driver side absorption, carpet, cover of the seat, under rear shelf, cover of lid and rear panel.
2. Half trunk absorption (carpet, passenger side, lid cover on)
3. Without any absorption.

In all three measurements were present the rear seats, that form the separation between the trunk and the passengers compartment. The measure is an average obtained by the values of five microphones positioned in the trunk compartment (see photo). In the graph are reported the shapes of the measure.

In the graph are reported the integrated time delay in milliseconds. The data were analyzed using the Schroeder back-integration algorithm. In some cases the shape was not so clear and the data are not considered like the 630 and 800 Hz bands where the time, reported in the tables below, indicates that there are possible standing wave. This hypothesis is also supported by the analysis in narrow band.


Graph of Time reverberation .

TR (ms) - No absorption

Hz	M. 1	M. 2	M. 3	M. 4	M. 5	nake
630	66	70	66	60	61	65
800	66	68	43	64	69	62
1000	36	36	33	35	24	33
1250	30	40	33	26	29	32
1600	37	37	35	31	30	34
2000	28	23	30	31	30	28
2500	27	25	24	31	30	27
3150	21	25	26	24	28	25
4000	23	31	35	28	25	28
5000	19	26	25	32	26	25

TR (ms) - Partial absorption

Hz	M. 1	M. 2	M. 3	M. 4	M. 5	Part.
630	66	66	70	69	71	68
800	58	59	57	56	62	58
1000		39	25	23	27	28
1250	31	28	33	31	32	31
1600	35	30	39	16	30	30
2000	29	27	29	27	30	28
2500	22	16	18	19	24	20
3150	14	14	15	15	16	15
4000	21	21	17	19	20	20
5000	19	19	18	19	20	19

TR (ms) - Normal Production

Hz	M. 1	M. 2	M. 3	M. 4	M. 5	dres
630	66	68	67	64	69	67
800	31	29	22	31	31	29
1000	27	19	19	24	31	24
1250	31	32	30	29	30	30
1600	32	31	32	28	32	31
2000	28	24	29	28	28	27
2500	19	17	20	16	20	18
3150	13	16	11	14	14	14
4000	19	19	17	18	20	18
5000	16	16	16	15	19	16

The data measured are used to obtain the average alpha coefficient of the absorption in the trunk compartment. The formula gives the average alpha coefficient.
In the last table below are reported the alpha values

$$T_{60} = \frac{55.3 * V}{c * \alpha * A}$$

introduced in the SEA model for central cavity trunk compartment.

Hz	No absorption	Partial absorption	Normal Production
630	0.30	0.28	0.29
800	0.31	0.33	0.66
1000	0.58	0.67	0.80
1250	0.60	0.62	0.63
1600	0.57	0.64	0.62
2000	0.68	0.68	0.70
2500	0.70	0.96	1.04
3150	0.77	1.28	1.42
4000	0.68	0.96	1.04
5000	0.75	1.06	1.16

The measurements are not taking in to consideration the exhaust air opening, measured separately.
The SEA model here considered is called "hybrid", it means that in the subsystem representing the cavity was introduced an experimental result instead of a simulation. Actually there are three different possibilities:

1. Introduce one average absorption
2. Introduce a measure absorption
3. Introduce an alpha coefficient for all the single part that forms the absorption package.

In the last case it is possible to have a single response of all parts and to know where are weakness, while the value is an average one that give only the total level. The model was developed following the second solution that give less information but best result, in fact is quite impossible to introduce an alpha coefficient, previously measure in the Kundt machines, due to the variability of the air gap between the sound package and the panels. In fact the air gap is one part of the absorption package that has to be take in to account.

The present reasearch project was developed with an earlier version of SEA software (AutoSea ver 1. xx) which now has evolved in the AutoSea 2 series with a much better graphical environment and powerful function for importing CAD or FEM models and faster solver.
FIAT partners in the project where Lear Italia (supported by SCS), FIAT CRF, Rieter Automotive.

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