ISSN 2176-5480

22nd International Congress of Mechanical Engineering (COBEM 2013)
November 3-7, 2013, Ribeirão Preto, SP, Brazil

SENSITIVITY ANALYSIS OF NUMERICAL AND EXPERIMENTAL COMPARISON BY NVH FINITE ELEMENT SIMULATION IN "TRIMMED BODY" TO DIFFERENT EXCITATION POINTS OF A VEHICLE IN THE FREQUENCY RANGE UNTIL 500HZ.

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Abstract. *We live currently a challenge for acoustics engineering automotive which means developing the car with the best acoustic performance at the lowest financial cost and operational. One of the ways to achieve this is cae from the "finite element simulation" tool to predict the NVH problems and help to preview difficulties in the developing models still at the design stage of the vehicle. To this the NVH engineer must be very attentive to several variables that can belong to this type of analysis. This study aims to understand the impact in excitation point zone - similar and different - in assessment of vibration and acoustic response on a "Trimmed-Body" vehicle when comparing their responses to similar and different points of excitement from experimental tests. For a first evaluation of the behavior of a vehicle vibroacoustic, the development of the functions of frequency response, known as inertance (a/F) where for the experimental case was used a impact hammer and one for the numerical case an impulsive force unitary, and thereafter are analyzed at the attachment points of the engine and suspension to the vehicle body. After that will be analyzed the impacts of this sensibility to acoustic response of the vehicle.*

Keywords: *Acoustic Analysis, Vibration Analysis, Finite Element, Trimmed-Body, Numerical Experimental correlation.*

1. INTRODUCTION

Currently noise, vibration and harshness (NVH) play an important role for the definition of the functional requirements of a modern vehicle as the customers are every day more and more demanding and one of the challenges of the car market is to provide efficient car with high perceived quality. This can be deployed into lighter body with a vehicle more silent. Nowadays, one of the most valuable criteria for vehicle quality assessment is based on acoustic emission levels: a car is judged comfortable also depending on the noise level transmitted inside. Consequently, there is a general attention to design criteria aimed at improving the structural-acoustic behaviour, in such a way to withstand the increasingly restrictive ergonomic standard.

With the goal of studying the behavior of numerical model of finite element this paper focuses on the application and validation of numerical methods for predicting the acoustic and structural NVH behavior of "Trimmed Body". A finite element model of the "Trimmed Body" has been developed using shell and solid elements to represent this segment of car.

The term "Trimmed Body" are used to refer to the use of an completely actual automotive or virtual FEM model.

In order to decrease the cost of the development process or late changes applied to the car, it is crucial to have reliable simulation in advance to the realization of the first physical prototype: in this work there will be presented standard methods for prediction of NVH behavior of "Body-in-White" evaluating the whole structure of the vehicle but using different levels of modeling complexity in order to extend the frequency range of the simulation. In particular, this study aims at investigating the numerical and experimental correlation in the extended frequency range between 10 and 500 Hz. This enlarged range has required the revision of some of the standard for the numerical simulation currently exploited up to 300 Hz in order accurately predict the systems response for the different excitation points that have been considered.

The term "Body-in -White" are used to refer to the use vehicle FEM model or actual but without doors and internal trims.

Also, with the aim to contribute the best practices of numerical job correlation with experimental results, this paper presents a review of the main points of this divergence process. Thus attempts to assess objectively as two analyst can obtain a higher gain in correlation development work.

The work in this paper may be seen as a precursor or perhaps a complement to the implementation of specialized tools for analyzing. For this purpose, and to assess the modeling aspects, many details that do not have any effect at lower frequencies have had to be considered.

2. METHODOLOGY

This study was motivated by the conflict in the final stages of development of a vehicle, the comparison between the results generated by the simulation team with those presented by the acquisition from experimental team.

In order to analyze what the possible causes of divergence in the measured results, vibrational and acoustic, this study intend to investigate the ways in which each team implements their work. Thus, among the possible methodologies liable to be adopted, it was decided in this study to evaluate the influence on the excitation point.

For this study we used a compact FIAT sedan vehicle.

The first step in this work has been the follow up on the job done in experimental tests. As the experimental phase have been designed for both providing the reference set of measurements for the numerical activity and, at the same time, assessing the levels of the dynamic stiffness of the various theoretical excitation points, many aluminum spacers have been used in order to make available for the ideal points adding the minimum mass to spoil the performance. As a consequence, the FE model have been updated with this devices in order to match the experimental results.

For initial assessment of the vibroacoustic behavior of a vehicle, in the early months of development, the frequency response functions, known as inertance (a/F), are analyzed, at the points of attachment of the suspension and the cradle-suspension localized in under-body assembly, to the body still in the “Body-White” configuration. Usually the finite element simulations are performed up to the limit of 300Hz. In the aim at increasing the range of inertance and acoustic analysis, enabling a more comprehensive analysis in NVH, the results by elements finites simulation were compared, in this work, with the results obtained in experimental measurements focused on the validation of this simulation methodology until the limit of 500Hz.

The vehicle model in Trimmed-Body is evaluated with the response measured at the points indicated in figure 2 and 3. Below it is shown the configuration to the layout of “BODY WHITE” vehicle used for the first results. This step is where we compare the numerical and experimental results with deferent and same point of excitation.

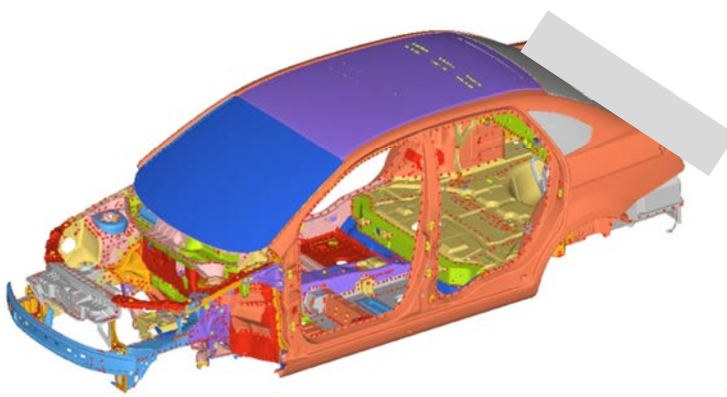

Figure 1. layout of BODY WHITE vehicle, FEM model.

Also, below, in the figure 2 and 3, it is shown the configuration of the experimental tests used to study the correlation with the numerical; it can be noted that different shape aluminum spacers have been designed and tooled in order to fit in the proper holes-mounting blocks.

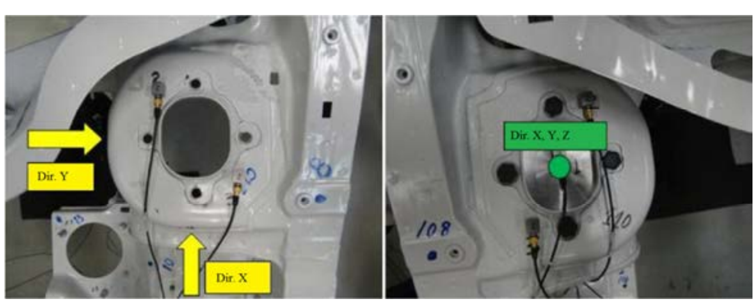

Figure 2. layout of experimental test, suspension zone (point 110).

ISSN 2176-5480

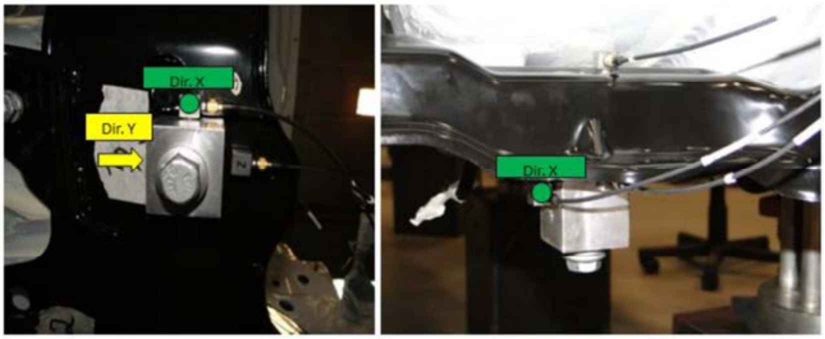

Figure 3. layout of experimental test, cradle- suspension (point 101).

With the goal of obtaining the best numerical experiment correlation, the finite element model has been constructed following exactly the guidelines originated from the experimental model. Below we can see the numerical model used to obtain the best gain in numerical experimental correlation, the Figure 04 and 5 referring to Figure 02 and Fig. 03.

Note through the figures, that represent the numerical model, that were made some assumptions (type: welding points, and placement of metallic blocks for better fit to the point of excitation) just to get the better correlation between simulation and experimental.

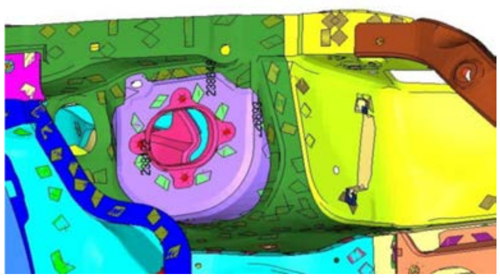

Figure 4 – Finite element model, suspension zone. (Ref. fig. 2).

Figure 5 – Finite element model, cradle- suspension zone (Ref. fig. 3).

Vibrational analysis of the system have been performed using standard MSC Nastran 2010. With this was done primarily a modal analysis of the entire vehicle, and then the data were treated in CRF VEIPROD 5.0® software for evaluation of FRF (Inertance).

The “Inertance” is a type of FRF where the response is measured based on the accelerations measured and normalized by the excitation force. The excitation for both, numerical model and the experimental model, was done using an impact hammer, the excitation was made to the side where the accelerometers were placed and use of an impulsive excitation.

The FE model consisted of 920000 nodes and required over 2100 eigen-modes to take into account all the modal behavior of the structure considering also the residual vectors to compensate for the higher order frequencies that are not directly extracted. The mesh size was tuned for the weaker part in order to have 8 elements for wavelength at 500 Hz.

With respect to the experimental data campaign, the full vehicle testing has been performed in the laboratory at NVH in semi-anechoic room, exploiting LMS Test Lab 11B.

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3. RESULTS

Below we can see the result for this vehicle model BODY-WHITE where we compared the experimental results with the numerical results by varying the excitation point. The results presented below were obtained by analyzing the region shown in Figure 2.

The blue line corresponds to the experimental result and the red lines the numerical results, and all results below are on a logarithmic scale.

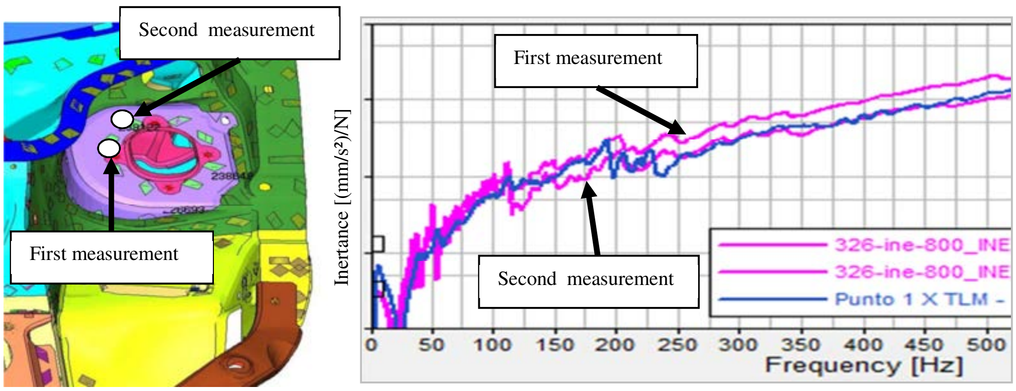

Figure 6 – Response of the numerical model (Ref. fig 2). Experimental curve (blue), first and second numerical measurement curve (red).

In the figure above we can see two red curves, a curve called "first measurement" is the response obtained with the excitement made the point marked on the left figure. Note that above 200Hz this answer has a distance from the blue curve (experimental measurement). So we made a second curve called "second measurement". This "second measurement” was made at the point shown in the figure on the left, and coincides with the excitation point of experimental test. Notice then that the correlation even above 200Hz much improved compared to the first measurement.

Below we repeat the test (Numerical / experimental) to another region of great importance (Point of large external power input) for the vehicle. But now we kept the measuring point numerical constant and vary the point of experimental measurement.

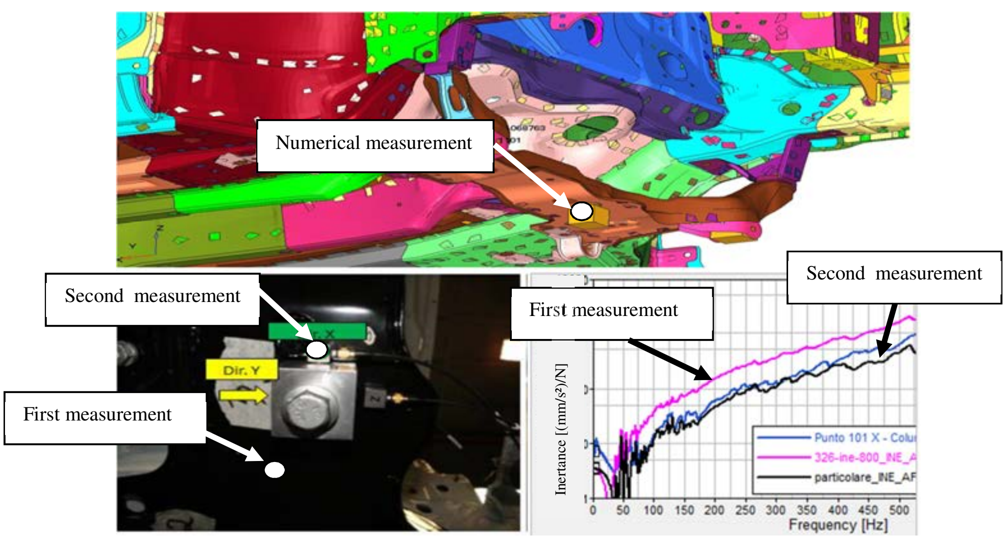

Figure 7. Response of the numerical model (Ref. fig 3). First experimental measurement curve (Red), Second experimental measurement curve (Black) and numerical measurement curve (Blue).

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Another test done on the vehicle, still in BODY-WHITE, in the region was the **Cradle** of this time respectful of the previous result kept the numerical result and vary the experimental test in search of a better correlation.

We note that the numerical result shown by the **blue line** got a good correlation varied area of application of the experimental test of the first point of excitement for the second, exactly on the aluminum block used to adjust the accuracy between excitation points comparing numerical and experimental .

Now, in the **second step** of this work we give below the impact on TRIMMED-BODY model (full vehicle) using the above correlation method. In Figure 8 we can see the model configuration Trimmed Body.

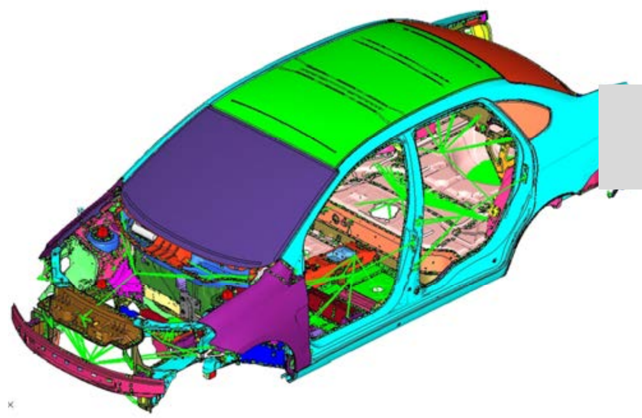

Figure 8. layout of TRIMMED-BODY vehicle, FEM model.

Using as a basis for the analysis Body Trimmed model and measuring the response of the region inertance presented in Figure 2, we obtained the response in the graph below, where the blue line is the experimental data and the red line numerical measurement data. By the graph we can see a correlation between the measurement with a considerable gain using as a basis the exact same point of excitement and all results below are on a logarithmic scale.

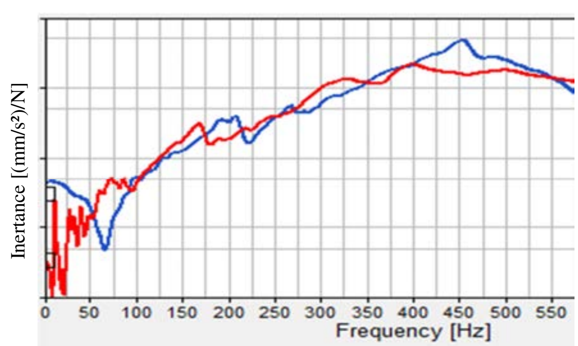

Figure 9. Trimmed Body model response in the region of the suspension. Experimental response (blue curve), Numerical Response (Red curve), (Ref. Figure 02).

The result of inertance presented above shows us that the evolution of the model from "Body-in-White" for a full version "Trimmed-Body" did not affect the correlation obtained previously.

Also, as Trimmed-Body model, we can see the result of inertance in the graph shown in Figure 10 from the measurement made in the region showed in Figure 3.

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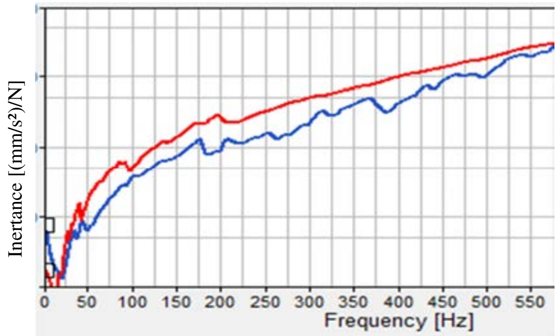

Figure 10. Trimmed Body model response in the region of the cradle- suspension zone. Experimental response (blue curve), Numerical Response (Red curve), (Ref. Figure 02).

There is still in this work by the earnings generated by the concern to obtain a good correlation in the phase of vehicle development when this was still in version BODY-WHITE, the quality of the acoustic results. In Figure 10 it is possible to observe a good correlation result generated by experimental numerical model "Trimmed Body".

In the present work a numerical model was created for the simulation of the vibro-acoustic behavior of the FIAT compact car shown in Fig. 8. In parallel an experimental measurement campaign was performed at the FIAT laboratories in order to allow the validation of the implemented procedure by comparison of numerical and experimental vibro-acoustic transfer functions, called Body Acoustic Sensitivities (BASs).

The BAS is defined as the ratio between the sound pressure level p(ω) inside the car body (in a specific point i) and the level of the structural excitation *f*(ω) that generated it (applied on the point j), expressed in dB:

$$BAS(\omega)_{i,j} = 20Log_{10}\left(\frac{p(\omega)_i}{f(\omega)_j}\right) \tag{1}$$

It is an intrinsic property of the system under linearity hypothesis and expresses the attitude of the system to transform structural excitations into noise inside the cabin. In figure 11 we can see the cavity model used for this analysis.

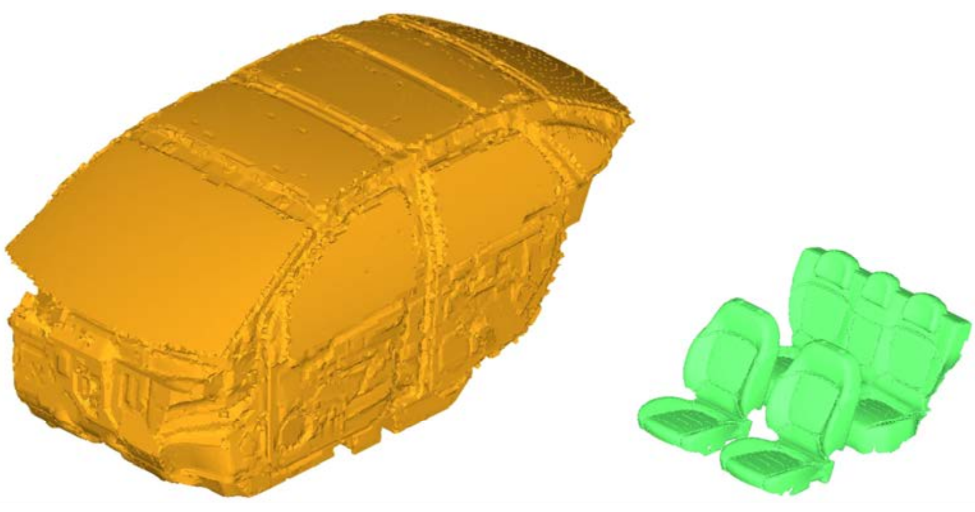

Figure 11. Cavity model base and the especial seat cavity.

Above we can see the cavity (fluid) used to represent the internal volume of the vehicle. This cavity this completed with the use of the dashboard and the cavity of the seat (shown in the right part of the figure).

After being held via NASTRAN SOL 103, the analysis on the model of the cavity, shown above, was performed the coupling (Structural and Fluid) via SOL 111 in NASTRAN. So using VEIPROD 5.0® (software for evaluation of FRF - BAS analysis). Thus, after data processing is presented we building the internal acoustics measured at the location of the driver's right ear. The **blue curve** shows the experimental measurements acoustic measurements and processed by LMS Test Lab 11B, this result was obtained by placing a microphone of high sensitivity in a spatial position that corresponds to the driver's right ear and without the human body influence (for both, experimental measurement and for the numerical).

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The **red curve** shows the numerical data. Both curves shape measures based on excitation "Z" region shown in Figure 2.

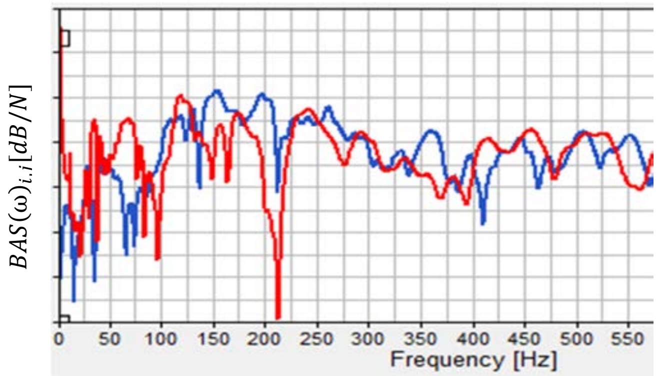

Figure 12. Acoustic Trimmed Body model response in the region of the suspension zone. Experimental response (blue curve), Numerical Response (Red curve), (Ref. Figure 02).

Observing the acoustic response in the Figure 12, we saw a good approximation of the numerical results (red curve) and experimental results (blue curve). Note for example that in addition to modal representations presented by the peaks of the curves, there is also a correlation as the tendency between them, this can be explained mainly by observing the frequency range that goes from 225Hz until 400Hz, this frequency range is remarkable that the numerical model perfectly describes the decrease of the acoustic response.

Also to answer displayed on the graph of Figure 13, we have the blue curve shows the experimental measurements of acoustic measurements and processed by LMS Test Lab 11B and the red curve shows the data of numerical simulation. Both curves shape measures based on excitation "Z" region shown in Figure 3.

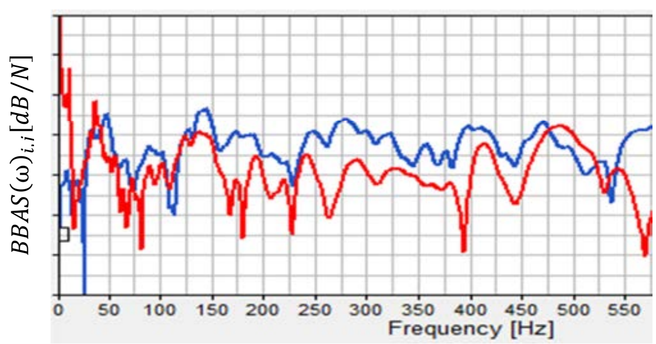

Figure 13. Acoustic Trimmed Body model response in the region of the cradle- suspension zone. Experimental response (blue curve), Numerical Response (Red curve), (Ref. Figure 02).

Also, observing the acoustic response presented in Figure 13, we can see a good results between the experimental and numerical answers. Although not present a correlation as good as that of Figure 12, the measured response with excitement in the cradle (figure 7), this is a region of greater instability because there is so rigid,but gives good results between 0 and 150Hz and above 400Hz.

4. CONCLUSION

The results that were shown here clearly show that work to validate a finite element numerical model is not only a mere superposition of the results is obtained in experiments with the simulation results. Rather, it requires a refinement of the model we have to consider various details which normally have a limited impact on the dynamic response of the structure at lower frequencies, but can have a huge impact on the midrange frequencies.

In this work we presented the influence on the results vibrational and acoustic due to the differences of the excitation points used in numerical analysis and that used for experimental measurement. This leads us to conclude that a study conducted jointly between the teams (CAE and Testing) project design already in aligning the information basis for good cooperation improves the performance of the expected results and facilitates the correlation process and rendering the simulation work in the NVH area more significant.

5. ACKNOWLEDGEMENTS

The authors thank the generous support of the Pontificia Universidade Catolica de Minas Gerais – PUCMINAS, the "Coordenação de Aperfeiçoamento de Pessoal de Nível Superior"- CAPES - "National Counsel of Technological and Scientific Development" and Fundação de Amparo a Pesquisa de Minas Gerais – FAPEMIG – "Foundation for Research Support of Minas Gerais", and also thanks for the FIAT Automóveis company.

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