# NVH TEST-CALCULATION CORRELATION OF AN ENGINE IN THE AUTOMOTIVE INDUSTRY

**Gabriel-Petru ANTON*; Ioana PETCU; Fabien SOREL**
Renault Technologie Roumanie – DIM / DAPEM NVH, Barba Center Sos. Pipera-Tunari, Nr. 1/VI, Voluntari, Jud. Ilfov, 077190, Romania.

***Abstract:*** *Nowadays, due to the market concurrence in the automotive field and the high customers standards, the acoustic comfort have become the one of the most important engineering require. This paper deals with the NVH test-calculation correlation, the finite element (FE) model updating of an engine and the vibration level (low and medium frequency range) on the engine/body interface points. The main objective for this approach is to obtain the absolutes values of the vibration level (low and medium frequency range) on the interface points using an updated FE model. Experimental and theoretical analysis used for this work, have allowed us to understand the real vibratory behavior and to obtain a new FE model more closed by reality. The final updating, the test-calculation correlation results and also the operational simulation and measurements level are presented within this paper.*

**Keywords:** finite element, automotive engine, NVH, modal analysis, correlation, updating, optimization.

## INTRODUCTION

The challenge of development time for cars requires to minimize the number of prototypes. The reduction of prototypes' loops can be realized if simulation is able to give predictable results.
The article explains an updating approach of a finite elements model based on the prototype powertrain measurements, with example of engine vibrations.

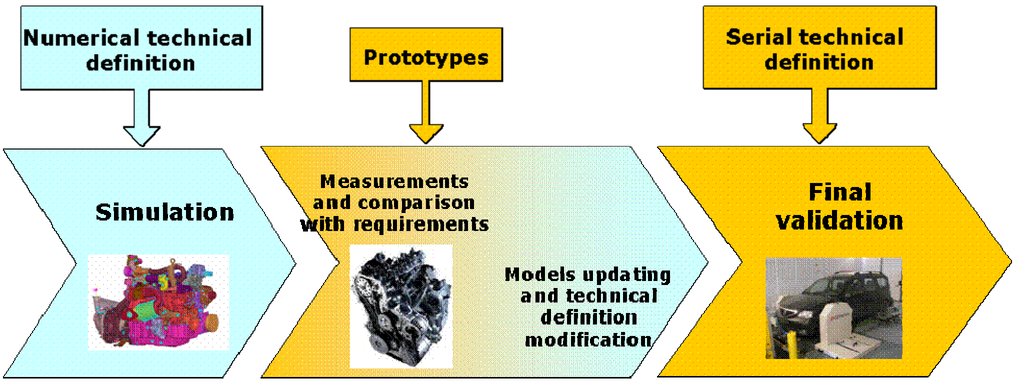



**Figure 1. NVH process for calculation & validation**

The vibrations transmitted to the body car by powertrain remain one of the main sources for low and middle frequencies. NVH numerical calculations are performed during the first steps of the development process of the powertrain. The purpose of the paper is mainly to present a general approach to update a FEM in low and medium frequency range, with two steps using like example the results of calculation of an engine bracket. These different steps for updating are described in the

* Corresponding author. Email: gabriel-petru.anton@renault.com

layout below (Figure 2), starting with experimental modal analysis and finishing with operational measurements.

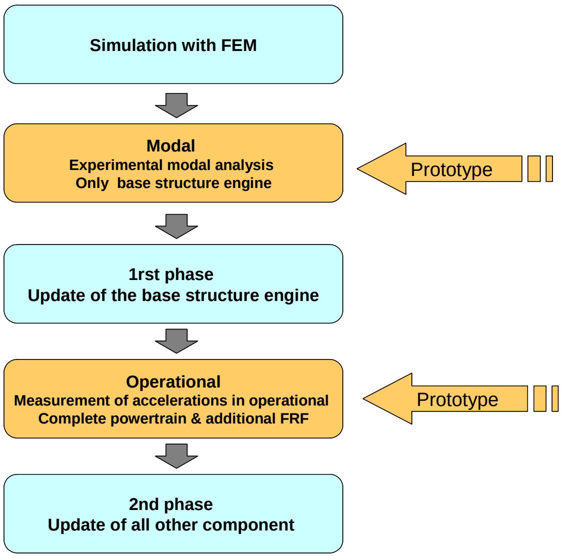



**Figure 2.** NVH process for FEM updating

## UPDATING ANALYSIS BASED ON EXPERIMENTAL MODAL ANALYSIS

Experimental modal analysis is the process of determining the modal parameters (frequencies, damping factors, modal vectors and modal scaling) of a linear, time invariant system by way of an experimental approach. The modal parameters may be determined by analytical means, such as finite element analysis, and one of the common reasons for experimental modal analysis is the verification/correction of the results of the analytical approach (model updating).
In order to have high quality measurements and confident results from Experimental Modal Analysis (EMA) we follow the next steps of validation: coherence and repeatability, linearity of the structure, rate of correlation synthesized with measured FRF, dissociation of modes with (AUTOMAC), visualization of modes shape.

### Example of EMA on a basic structure of an engine

The main reason for EMA in our case is to offer experimental results for the FE model updating process. The approach for EMA performed on engines starts with measurements on single parts and after that, we test the engine base assembly in free-free equivalent conditions.

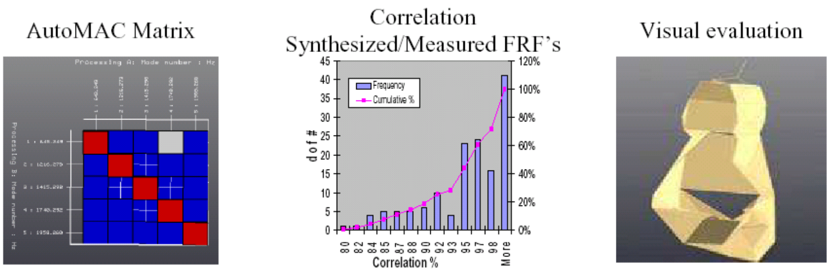



**Figure 3.** Modal validation methods

Taking into account the validation results obtained (see figure 1), low values for the off-diagonal elements of the AutoMAC matrix, high values for the correlation Synthesized / Measured γ/F transfer functions and physically realizable modal shapes we can conclude that the extracted modal base is valid.

**Example of updating on a basic structure of an engine**

By using the EMA results, we update the FE models by modifying local density and stiffness of materials and by improving the model of linked between the different parts. We superpose the models test and calculation in order to see the differences and to correlate the two models. For this, we use the CAE special software, setting the responses in frequency and the parameters to be changed within the updating analysis.

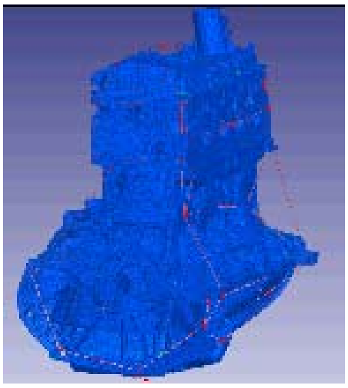


**Figure 4.** Test-calculation correlation

The updating analysis is based on two criterias (MAC criteria and frequency criteria). We intend to decrease the frequency difference between the experimental and FE model and to have the same modal shapes, for each single part and for the assembly.
The results of correlation at the end of updating for the base structure are presented below in the Table 1.

**Table 1.** Correlation test-calculation of the base structure, at the end of the updating analysis

| FEM (FREQ en Hz) | EMA (FREQ en Hz) | Diif freq [%] | MAC [%] | Deformations / shape |
|---|---|---|---|---|
| 839 | 814 | 3,15 | 94,1 | Bending around Z |
| 1015 | 1013 | 0,20 | 88,9 | torsion |
| 1075 | 1102 | -2,50 | 82,7 | Bensing around X |

The evolution of the correlation after the 1st step of updating is given in the graph below.

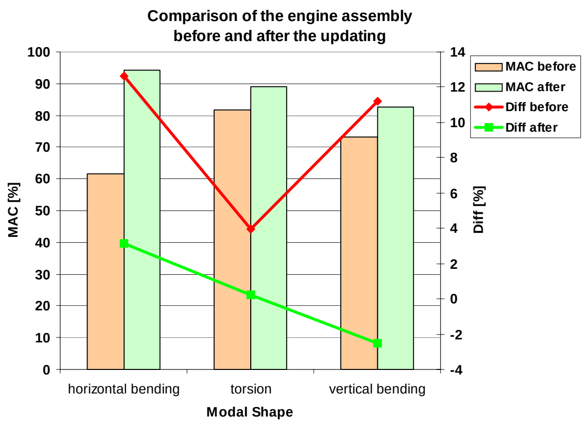



**Figure 5.** Comparison test (EMA) - calculation

## UPDATING ANALYSIS BASED ON FRF AND OPERATIONAL MEASUREMENTS

Using the FE model (of basic structure of engine), updated in according to EMA results, we built the FE powertrain model and perform a modal analysis and a vibratory calculation in low and medium frequency on the engine suspensions (interface points between engine - body), followed by a first test – calculation correlation (see point 3.2). The operational measurements results are obtained respecting a specific procedure described in general lines below (see point 3.1).

### Operational measurements

Data acquisition is the collection of data in real time from specific types of sensors so that the information can be stored and further processed in a computer.
The main components of a DAQ system (Data Acquisition system) are presented in the figure 6:

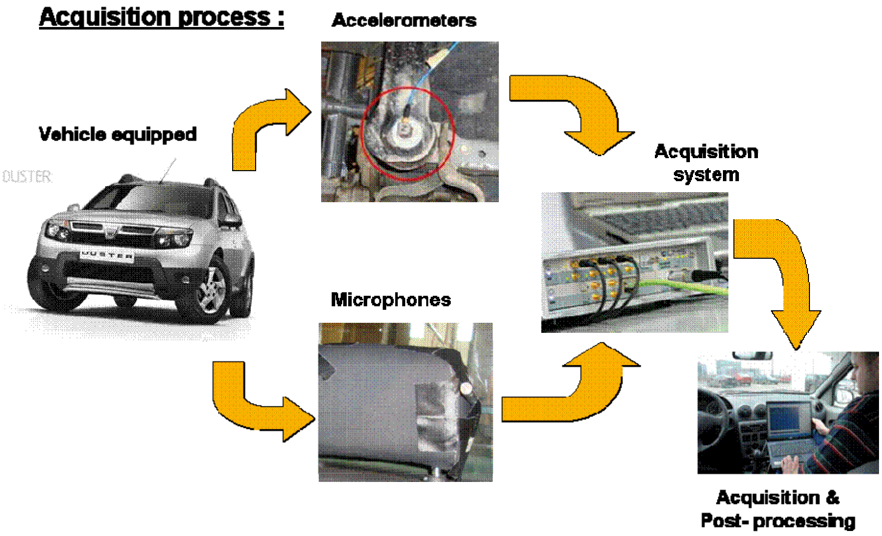



**Figure 6.** Acquisition process - measurements

### Sensors

The most used type of sensor for NVH measurements is the three axis piezoelectric accelerometer.
The DAQ hardware used when performing a NVH measurement is a LMS SCADAS Mobile SCM05 mainframe with 24 channels, high-speed Ethernet interface (transfer rate at 14 Msamples/sec). The SCADAS is equipped with 4 V8 modules; which support ICP sensor (offering a maximum sampling rate of 51,2 kHz).
The specific software for acquisition and post processing is also a LMS product, called Test LAB.
Performing a NVH measurement, either for CM correlation, either for validation of different parts or evaluation of the behavior requires the following steps (Figure 7):

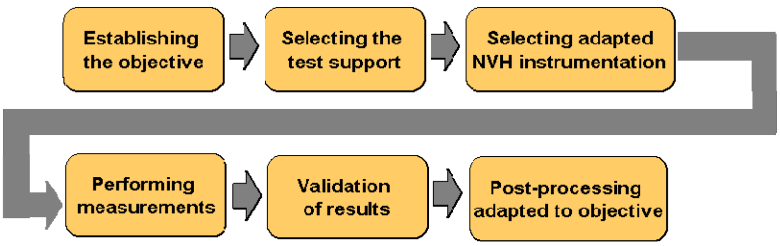



**Figure 7.** NVH measurement procedure

**Establish the objective**: in our study, updating of FEM for vibrations at engine mounting points (low& middle frequency range).

**Selecting and validating the testing suppor**t are essential steps in performing a proper C-M correlation. At this point we have to ensure that the testing support and the simulation model correspond, meaning that we are using the same technical definition for the rest of the process.

**NVH instrumentation** involves mounting at specific position sensors like mono-axis or three axis accelerometers, microphones, torque meters, pressure sensors. For a simulation/test correlation of the engine brackets, usually only accelerometers are required. In addition to the engine mounting point, other localization for accelerometers are recommended by simulation to have some more information about the local operational resonance.

**Performing the measurement** is the process of making data acquisitions in repeatable condition: For the specific case of a simulation/test correlation of the engine brackets, we use a full load run-up in third gear. FRF are done also to confirm the local resonance of the vibration in operational.

In order to **validate a measurement**; there are two steps: checking that the acquired signals are not saturated and that there is no significant dispersion between consecutive acquisitions.

**Post-processing** is colormap 3D graphs that give levels of vibrations depending engine speed ad frequency, and 2D graphs for tracking of order 2 and octaves 250Hz and 500Hz depending engine speed. Spectrum represents transfer function. That post-processing is similar to simulation post-processing for correlation.

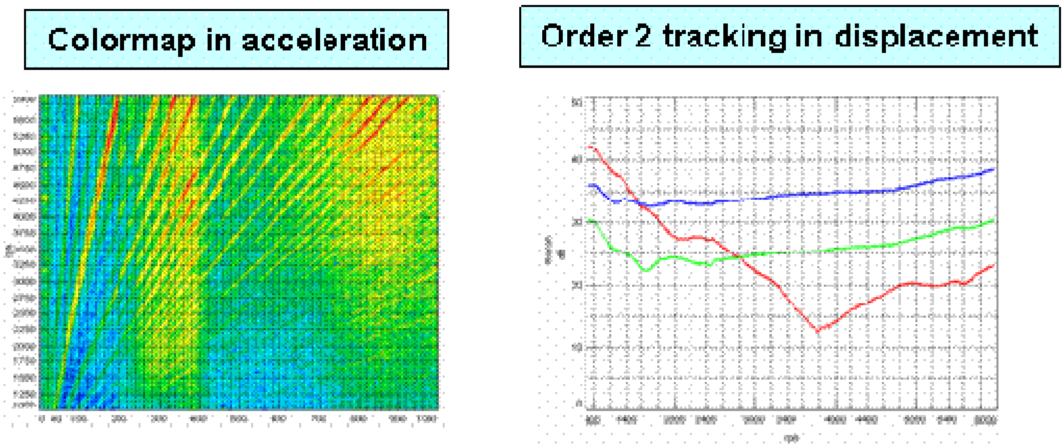



**Figure 8.** Example of colormap and order 2 tracking for engine mounting point vibrations

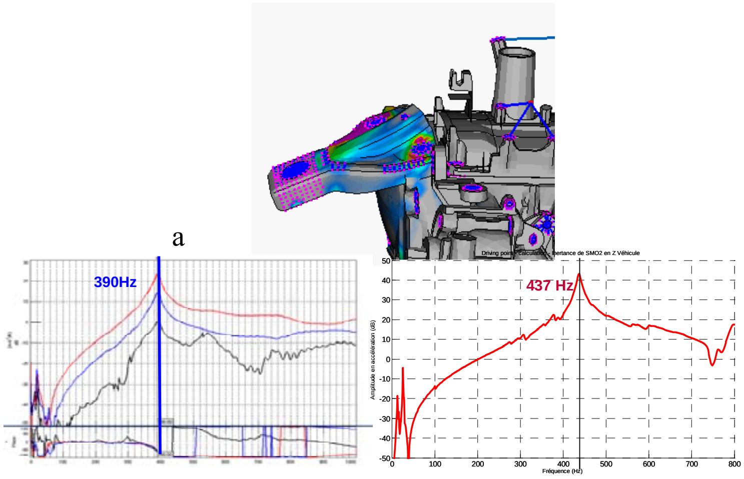
## COMPARISON OF TEST AND CALCULATION RESULTS

### Vibratory calculation (FRF and operational calculations)

At the end of the vibratory calculation, integrating test and analysis, it is comparing numerically and experimentally obtained data. We identify if the updating in frequency and amplitude, based on FRF and operational measurements, is required.
In order to obtain information about the structure of the engine (natural frequency, damping, stiffness and mass behavior), it is necessary to have a **driving point** on the different parts.
For the calculation of vibratory levels, its are taken into account the efforts from the chamber combustion, liner cylinder and crankshaft bearings. These efforts are calculated using the cylinder pressure at the different engine speed.
The vibratory calculation give us the information concerning the amplitude of the vibrations on the three engine suspensions, taking into account two ranges of frequency: low frequency 0 – 200 Hz named **booming noise** and medium frequency divided in 250 Hz octave (**rumbling noise**) and 500 Hz octave (**whirring noise**). These values of amplitudes have to fulfilled the customer specifications.

### Example of a driving point curve on an engine mounting bracket (on timing side)

Vertical line indicates the 1st natural frequency of the part : 390 Hz for test (Figure 9 - b) and 437 Hz for calculation (Figure 9 - c). A first updating in FRF can be perform for a better frequency and amplitude positioning.




a b c

**Figure 9.** Driving point on the engine mounting bracket

**Example of tracking H2 on an engine mounting bracket (on the timing side)**

The main harmonic for 4 stroke engine with 4 cylinders is H2 (second order). An exemple of a **tracking H2** (comparison test and calculation) on the engine mounting bracket is given in the Figure 10.

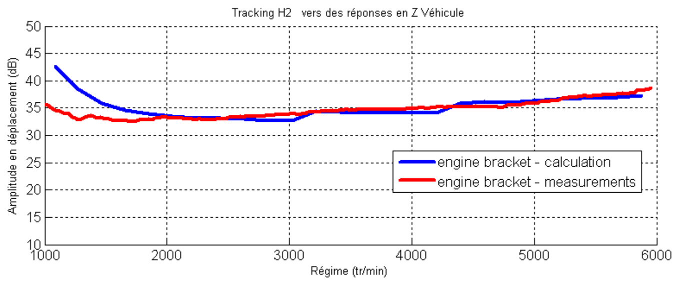



**Figure 10.** Tracking H2 on the engine mounting bracket

**Example of sonogram colormap on an engine mounting bracket**

**Sonogram and Peak Hold** – are used for medium frequency range, in order to identify the contribution of the harmonics; an example on the engine mounting bracket is given in the Figure 11. The red color indicates the highest level of vibration on the part considered on the engine. The vertical line show the first mode of the engine mounting bracket at the different values of the engine speed. The eigen modes of engine bracket at measurements and calculation can be noticed also on the sonogram colormap.

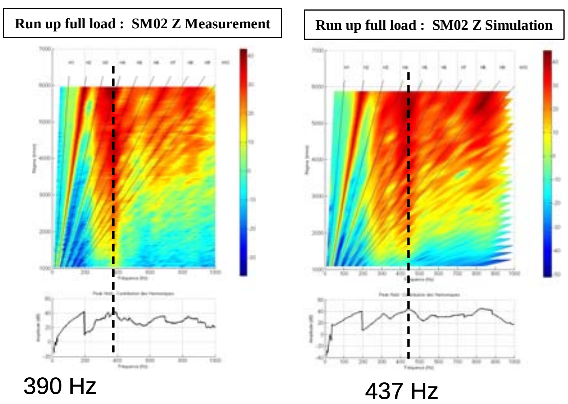



**Figure 11.** Sonogram and Peak Hold

## Updating technique based on FRF and operational measurements

From FRF point of view a positioning in frequency and amplitude is required. For this, into a first step the mass and stiffness are checked, then the modeling of FE model and adjusting of damping can be usefully in updating process. For example, the modeling of connection points on the engine (of the engine bracket) decreases the frequency from 437 Hz to 385 Hz and comparing with test value (390 Hz) it results a good correlation in frequency (see Figure 12).

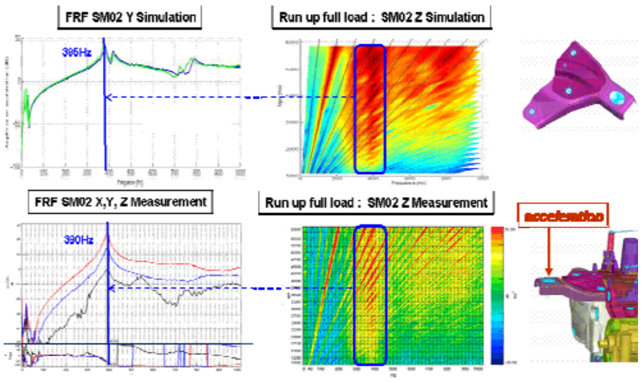



**Figure 12.** Test – calculation updating in frequency

From operational calculation point of view a positioning in amplitude in according to the engine speed is required. The mass checking of components parts, adjusting of rubber stiffness of body-engine interface, adjusting of the stiffness of the mobile parts of accessories face and the engine excitation can be used in the updating process.

## Example of synthesis test-calculation correlation (on an engine mounting bracket)

At the end of the updating process we perform a last test-calculation correlation from operational point of view. In the graphs below the amplitudes at low (at 3000 rpm and 6000 rpm) and medium frequency (at 3000 rpm) are represented (see figure 13). We have a good correlation at low frequency and medium frequency, exception being SMO2 X – Octave 250 Hz.

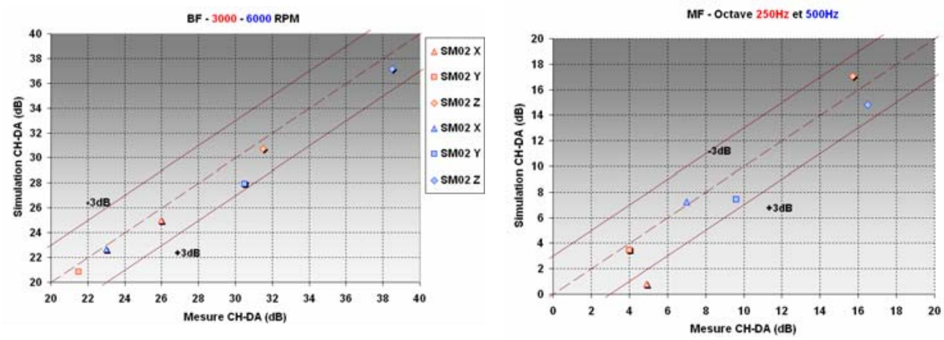



**Figure 13.** Synthesis test-calculation correlation

## CONCLUSIONS

The methodology presented within this paper permit to perform the predictable FE models due to the updating based on EMA, FRF and operational measurements, providing a good acoustic prestation / price ratio and avoiding at maximum the performing of the prototype and
the measurements.
The approach applied on the engine mounting bracket can be used to update all the components parts of a powertrain.