ADVANCED CAPABILITIES OF META FOR NVH POST-PROCESSING & SUBMODELLING

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ABSTRACT –
NVH behavior plays an important role in all phases of vehicle design. Accordingly, the use of Finite Elements for NVH analysis has become necessary for meeting efficiently the desired standards.

As a consequence, the increasing significance of NVH simulations imposes the need for bigger and more accurate models which contributes even more to the generation of vast amount of results, an issue inherent to NVH analysis. Owing to that fact as well as due to the use of multiple software tools, NVH post-processing can be very demanding and time-consuming.

This paper presents NVH oriented 3D and 2D tools embedded in META. Capabilities such as the support of related results and the derivation of more variables, the easy and fast calculation of modal responses, the calculation of Acoustic responses involving also the coupling between the air cavity and the structure, the modal correlation (calculation of MAC), are discussed. Moreover, the use of all these tools is related to high performance, an aspect of paramount importance for handling such big volumes of data. Modal submodelling, necessary for reducing the model size and simulation time, can be also conducted. Finally, the extensive support of diverse results from Nastran design optimization, so frequently used in NVH analysis, is also presented.

TECHNICAL PAPER -
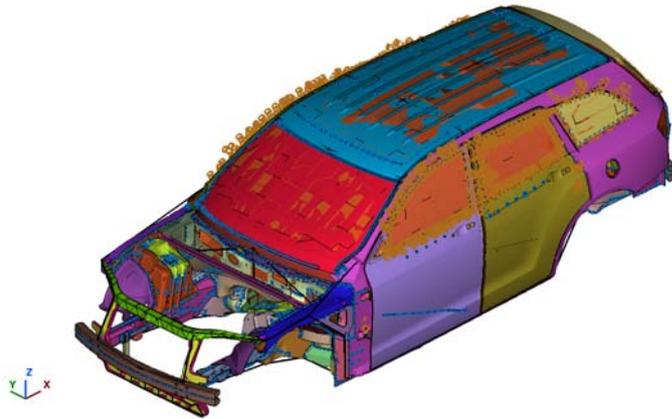
1. INTRODUCTION

The post-processing and analysis of NVH results can be a cumbersome and time-demanding task, a fact that stems from the combined effect of the following factors:

- NVH is related to the generation of vast amount of data which often imposes certain limitations to the post-processing due to poor performance of post-processors and restrictions on memory consumption
- Getting an adequate insight of NVH results is difficult due to, for example, it can involve different types of variables that must be visualised simultaneously. Another example is the post-processing of Nastran SOL 200 design optimisation results, so frequently used in NVH. In general, NVH analysis demands advanced post-processing capabilities
- Certain NVH calculations need considerable time when performed by Nastran itself (eg: calculation of panel participations), therefore, it is preferred to conduct them separately having also the option to carry out what-if analyses faster and easier. Moreover, there are also tasks involving calculations that cannot be performed within Nastran at all (i.e. the creation of modal models)
- Conducting, however, calculations away from the main solver implies the use of multiple software, thus, giving rise to the complicated nature of NVH post-processing

- A considerable number of reports have to be generated to communicate the results of NVH analyses. However, the creation of reports can be a tedious and a time-consuming process.

This paper outlines how META addresses successfully the above issues which are inherent in NVH post-processing. New META tools that facilitate most common NVH analysis needs are presented. The use of these tools in conjunction to META's outstanding performance along with its advanced features and unique automation capabilities provide an integrated suite for efficient NVH analysis.

The NVH model used in this paper is shown in Figure 1 and it includes:

Nodes: 462617

Shells: 393217
    Quads: 368611
    Trias: 24606

Solids: 18787
    Tetras: 1614
    Pentas: 667
    Hexas: 16506

Structural Modes: 200
Cavity Modes: 12

Figure 1 – NVH model

The post-processing has been conducted on the following platform:
Operating System: Linux Fedora Core7, x86_64, 2.6.23.1-21.fc7
CPU: Intel(R) Core(TM)2 Duo CPU E6750 @ 2.66GHz
RAM: 8 GB
Graphics: NVIDIA GeForce 8800 GTS
OpenGL Version: 2.1.2 NVIDIA 169.12

2. EVALUATION OF NORMAL MODES RESULTS

Automated reporting for normal modes

As soon as normal modes have been calculated by Nastran, there are certain checks that need to be performed in order to evaluate if the model is properly defined or not and thus, the user can decide accordingly whether to proceed with further post-processing, or to modify and correct the model.
These checks may include the recognition of zero modes for the structure and the cavity fluid as well as the visual inspection of a number of modes. These actions have been automated with a META script and a report in HTML format is also created including the necessary information. The required input for this script is provided through a user toolbar that is depicted in Figure 2. The script recognises the zero modes and prints relevant warning messages (Figure 3) to the report and then a number of structural (Figure 4) and cavity modes (Figure 5) are shown as images.
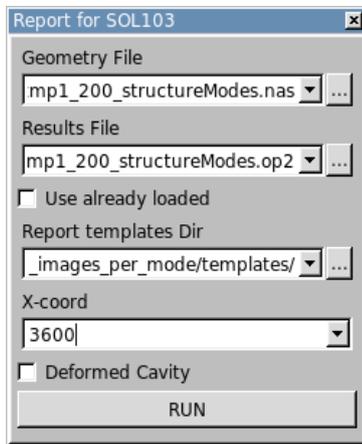Time required for running the script: 83 sec.

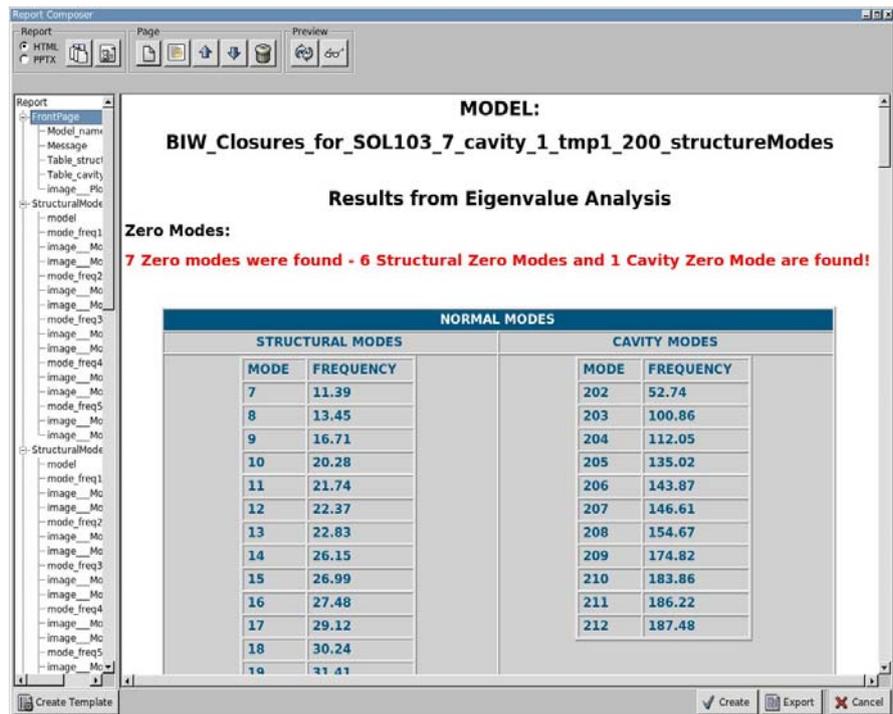Figure 2 – User toolbar for automated reporting on Normal modes analysis

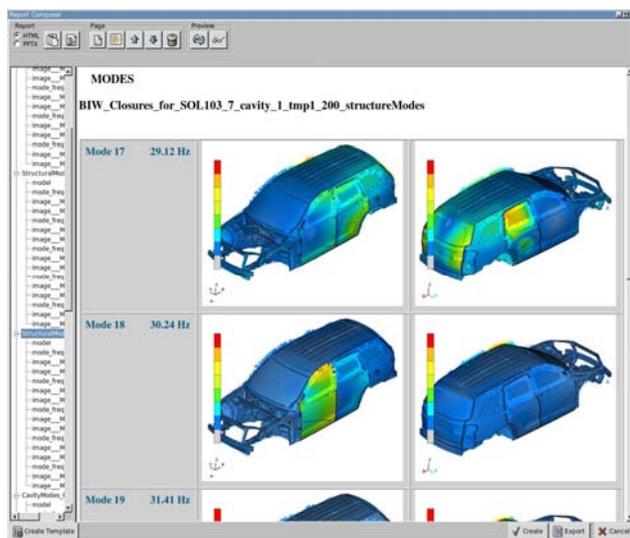Figure 3 – Normal modes listing inside the report

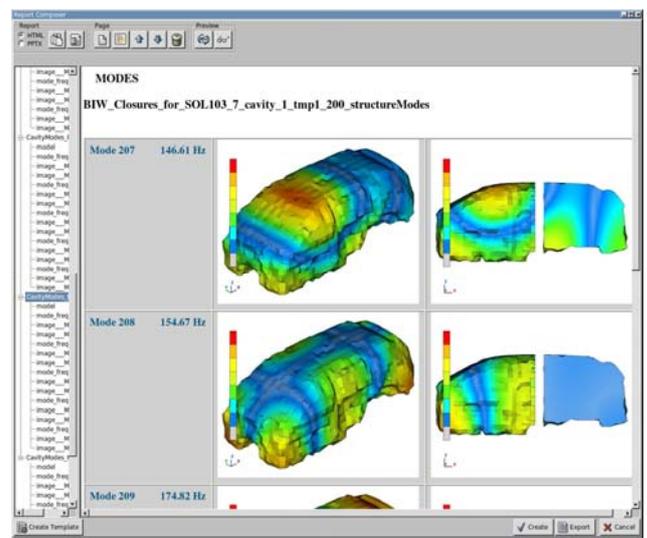Figure 4 – Structural modes inside the report

Figure 5 – Cavity modes inside the report

Modes correlation – Modal Assurance Criterion (MAC)

As a next step, the structural normal modes that are calculated should be correlated with those extracted from modal testing.
The geometry of the test model is represented as a PLOTEL mesh and it is input in META from a Universal format file.
The normal modes of the FE model as well as the ones calculated from the modal testing (residing in universal format file) are fed as input to the Modal Correlation tool. The PLOTEL nodes are selected as the node-set to calculate MAC values and automatically META performs the node pairing with the corresponding nodes of the FE model based on proximity. The MAC values are calculated and a list with the best mode pairs satisfying criteria for MAC value and frequency difference appears under the Mode Pair tab (Figure 6). A MAC and a Frequency Difference plot are also created (Figure 7 and 8).
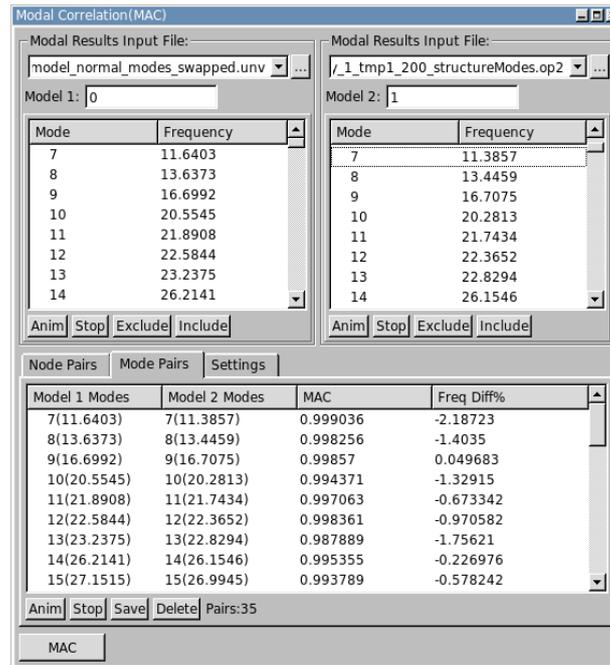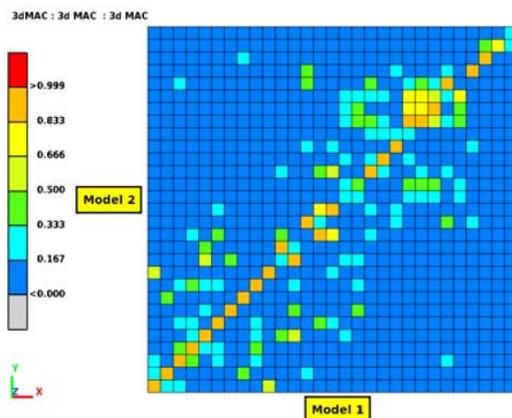
Figure 6 – Correlated mode pairs table
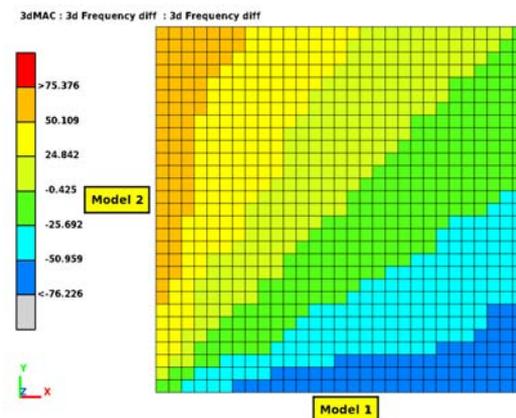

Figure 7 – MAC plot

Figure 8 – Frequency Difference plot

Time required for the calculation of MAC values for 137 node pairs and for 28 modes from each model: 5 sec

Simultaneous animation of multiple normal modes

For the cases where the correlation results do not provide a clear view of which mode of the FE model corresponds to a test mode, a visual inspection will be necessary to acquire a better insight. In META, it is possible to simultaneously animate multiple modes in different 3D windows without loading the model multiple times, hence without having any negative impact to the required memory. Figure 9 displays a test mode at 39.8 Hz and 2 FE modes close to that frequency. Both FE modes correlate well with the test mode as shown from the MAC plot.

It should also be noted that the instances of the model inside the 3D windows may display different parts of the model. In this way, it is possible for example to keep visible in one 3D window only the fluid cavity part and animate a cavity mode, while in another window keep only the structure and view a structural mode.

Time required for animating 2 FE modes and 1 test mode (PLOTEL mesh) simultaneously (18 angle increments): 2 sec
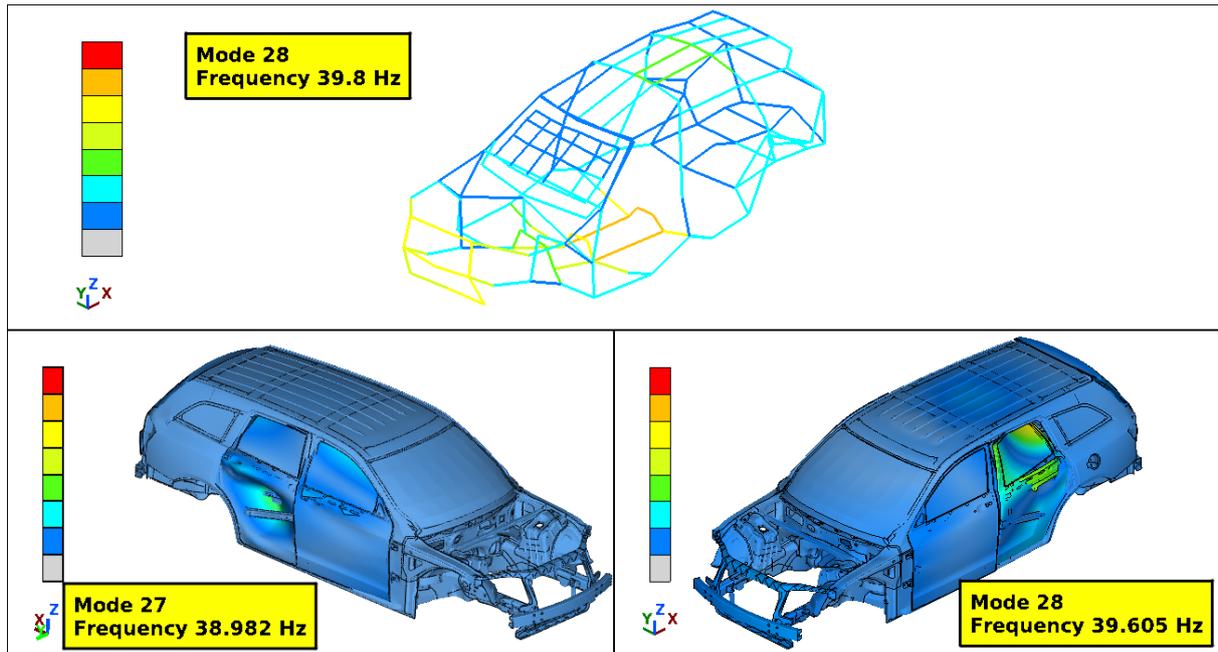
Figure 9 – Display / animation of multiple modes as different instances of the same model and the test model

2. FREQUENCY RESPONSES

Next to the normal mode analysis, the structural and acoustical frequency responses are calculated from the eigenvectors through the "Modal Response" tool of META. This paper, describes only the calculation of acoustical responses since this covers a broader range of functionality related to the Modal Response tool. However, the same procedure can be followed for the calculation of structural responses.
The calculated results are also compared with those output from Nastran.

Required input for the calculation of acoustic responses

The following input must be provided for the calculation of acoustic responses:

1. Normal or complex modes. Frequency responses can be calculated based either on normal or complex modes results. The eigenvectors can be read either from a Nastran op2, a Nastran punch or a Universal file format. For the case presented here, normal modes (both structural and acoustical) are input from an op2 file and listed (Figure 10).
A default modal damping ratio is applied (0.02) which can be modified by editing the value of each mode separately from the list or by specifying one of the available TABDMP1 tables under the Tables tab.
The modes that should be used for the calculations can be controlled easily through Include / Exclude buttons.

2. Dynamic loads: The dynamic loads can be either read from a Nastran Bulk file or can be created in META. These loads are listed in tree form where the parent item corresponds to a loadcase. For the current example, the loads are input from a Nastran file and at the same time the frequency range is also adjusted according to the frequency range specifications existing in the Bulk file (Figure 11).

3. Response DOFs. One fluid grid is added to the Response DOFs list for the calculation of the Acoustic Responses (Figure 11).

4. Fluid-Structure coupling data: For the definition of the fluid-structure coupling data inside the "Acoustic coupling" tool, the following three options are available:

- The use of available data in Nastran punch format. In this case these data are output in the form of Nastran DMIG keywords.
- The use of available data output in Akusmod format.
- Creation of the fluid-structure coupling inside META. The necessary input to achieve this includes a group with the fluid elements, a group with the structural elements forming the cavity and a search distance parameter as a percentage (%) of the minimum fluid element length.
    Time required to create fluid-structure coupling with META: 99 sec

It should be noted also that META allows for modular fluid-structure coupling. In other words, it is not necessary to include all coupling information only in one data set. Multiple coupling data sets can be created between different groups and all of them will be accounted for when acoustic responses are calculated. The coupling data sets among the listed ones that will be used for the acoustic responses can be controlled easily through Include / Exclude buttons (Figure 12).
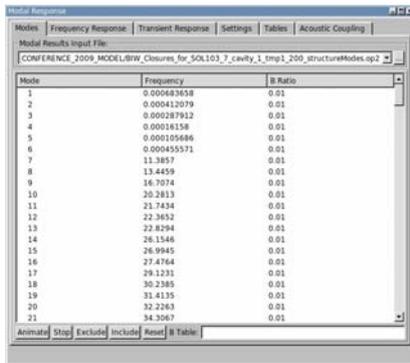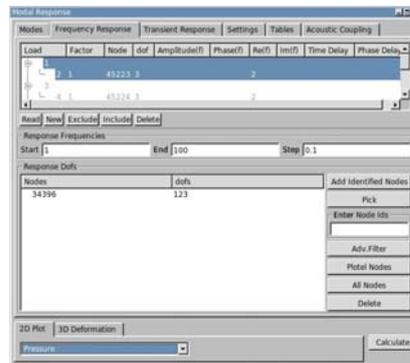

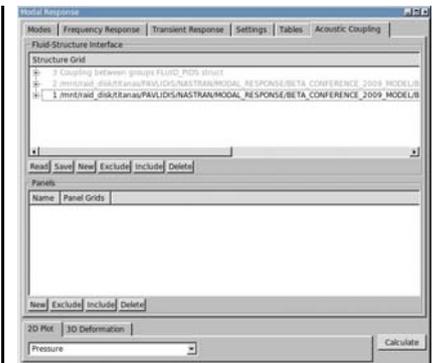Figure 10 – Modes list

Figure 11 – Loads & Response DOFs

Figure 12 – Acoustic coupling data sets

Calculation of acoustic responses

The acoustic pressure for the fluid node 34396 is calculated in META for the following three different fluid-structure coupling data sets which are related to the same group of elements and performed respectively by:

Nastran
Akusmod
META

These responses are plotted in Figure 13 and compared against the respective response as calculated by a relevant Nastran SOL111. It can be seen that the response originally calculated by Nastran SOL111 is identical to the response calculated by META using the coupling data produced by Nastran which absolutely verifies the acoustic response calculation by META.

The correlation of the responses which are based on the Akusmod and the META coupling data is also accepted and satisfactory.

Time required for the calculation of the acoustic pressure for each of the coupling data sets: 60 sec.

It should be mentioned here, that this is the maximum time and corresponds to the calculation and plotting for the first time. For the calculation of an acoustic response at another node using the same coupling data, the time drops dramatically (around 10 sec). Time required for plotting the acoustic pressure from the Nastran punch file: 25 sec. The relevant punch file is 1.05GB and the time reflects only the loading of the file. After the file is loaded, the time to plot any variable from that file is negligible (1 sec).
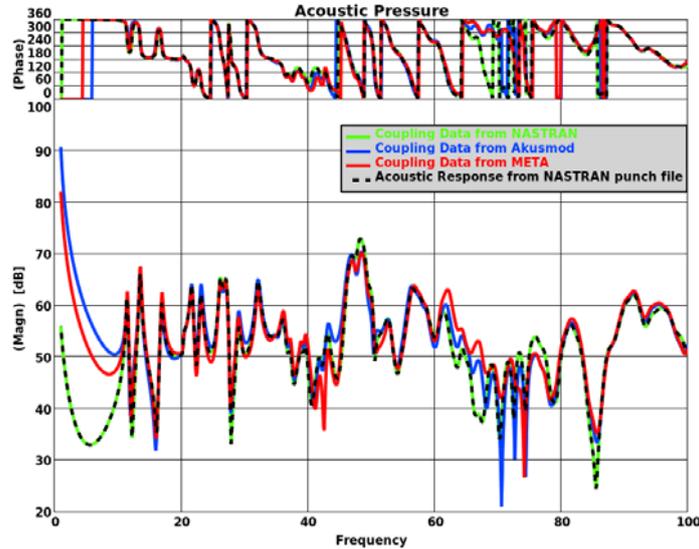

Figure 13 – Acoustic pressure for the same node and different coupling sets

Figure 14 depicts 20 structural mode participations and Figure 15 depicts the fluid mode participations for the fluid node 34396 as calculated by META and based on the cavity data created by META. The total acoustic response is also plotted.

Time required for the calculation and plotting of 200 structural mode participations: 5 sec
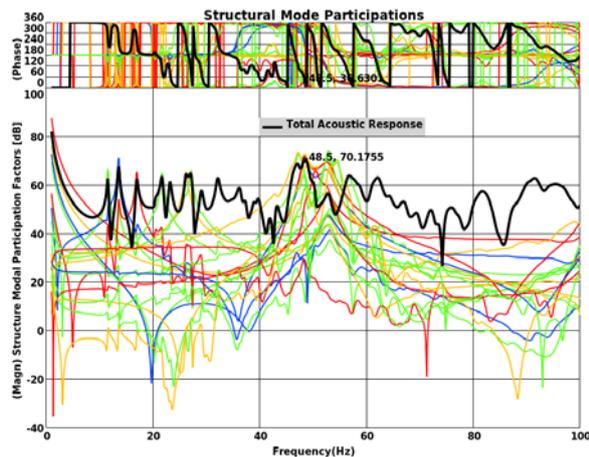Time required for the calculation and plotting of 12 fluid mode participations: 3 sec

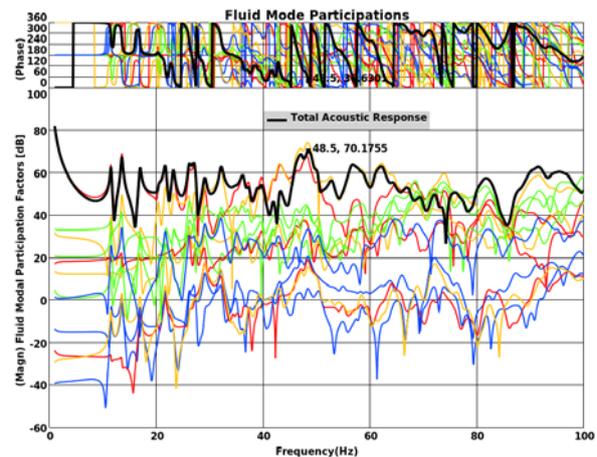Figure 14 – Structural mode participations

Figure 15 – Fluid mode participations

Figure 16 is a polar plot including structural mode participations against the total acoustic response at node 34396 and at 48.5 Hz where a peak pressure occurs. It can be clearly seen that the dominant mode for that frequency is Mode 37.
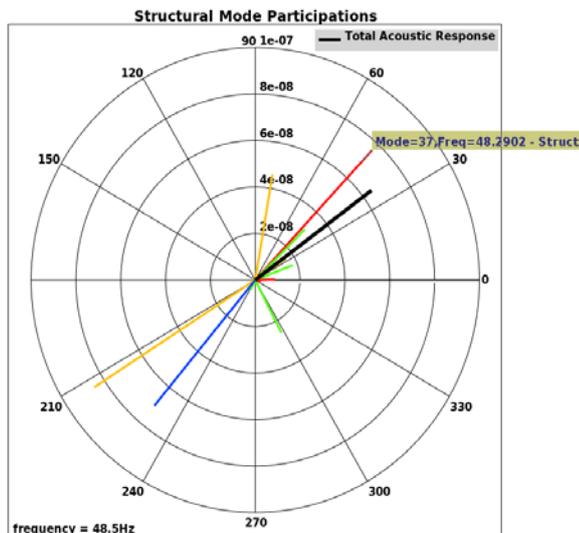
Figure 16 – Structural mode participations at 48.5 Hz

Creation of 3D frequency response results (operating modes)

Through the Modal Response tool, it is also possible to calculate the frequency response for all nodes of the model thus enabling the animation of those results for certain frequencies (operating modes).
Figure 17 shows the respective operating mode at 48.5 Hz for the structure and the fluid, as calculated by META, along with the dominant mode 37 at that frequency.

Time required for the calculation of structural operating mode at 48.5 Hz (18 angle increments): 150 sec
Time required for the calculation of the fluid operating mode at 48.5 Hz (18 angle increments): 165 sec
Time required for the simultaneous animation of the operating modes and mode 37 (18 angle increments): 2 sec.
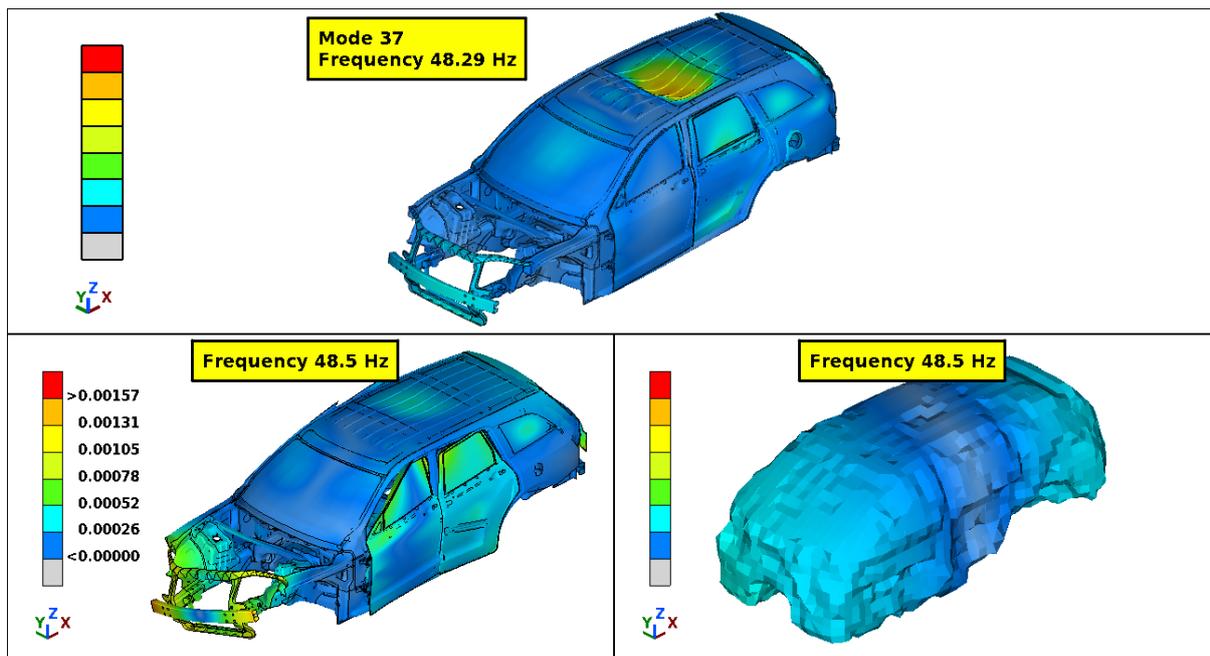

Figure 17 – Operating mode at 48.5 Hz and mode 37

Panel Participations

For the calculation of panel participations, the different panels have to be defined in META (Figure 18). The Advanced Filtering tool provides flexibility and ensures that any panel definition is feasible.
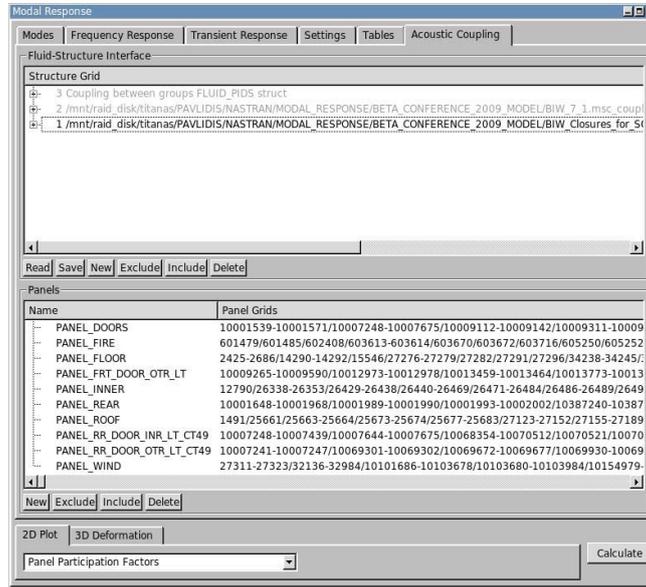

Figure 18 – Panels definition in META

In Figure 19, the panel participations as output by Nastran SOL111 are compared with those calculated by META for exactly the same panels using the Nastran coupling data.
The corresponding results are identical and that provides verification for the calculation of panel participations in META being correct.

Time required for the calculation of participations for 10 panels: 70 sec
Time required for plotting participations for 10 panels from an already loaded punch file: 2 sec.

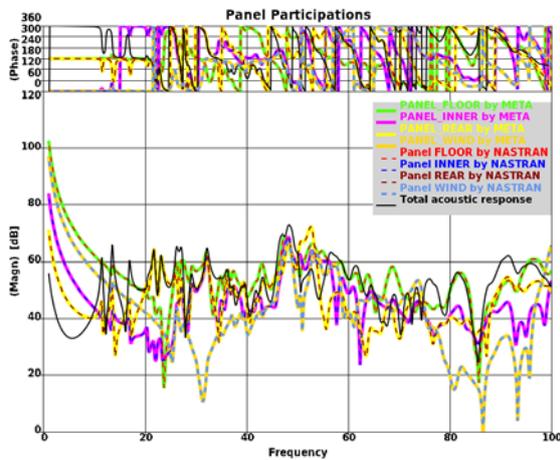Figure 20 is a polar plot of the panel participations at 48.5 Hz.

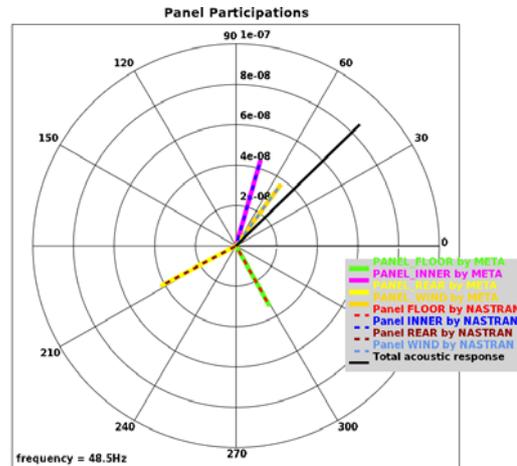Figure 19 – Comparison of panel participations by Nastran and by META

Figure 20 – Panel participations at 48.5 Hz

3. OTHER CAPABILITIES FOR POST-PROCESSING NVH RESULTS

Visualisation of Panel & Grid Participations results

Figure 21 shows the fluid cavity as well as the structure. Grid participations at 50 Hz as output by a Nastran SOL111 analysis, are displayed as deformations while, at the same time, panel participations are contour plotted on the structure. The corresponding acoustic pressure results are also plotted on the fluid cavity mesh.
In this way, all necessary information is displayed at once on multiple instances of the same model allowing for a better insight to the NVH results in a simple and fast way without any negative impact to the memory.
Time required for reading the results for these 3 variables and for 18 increment angles (including the loading file process): 10 sec
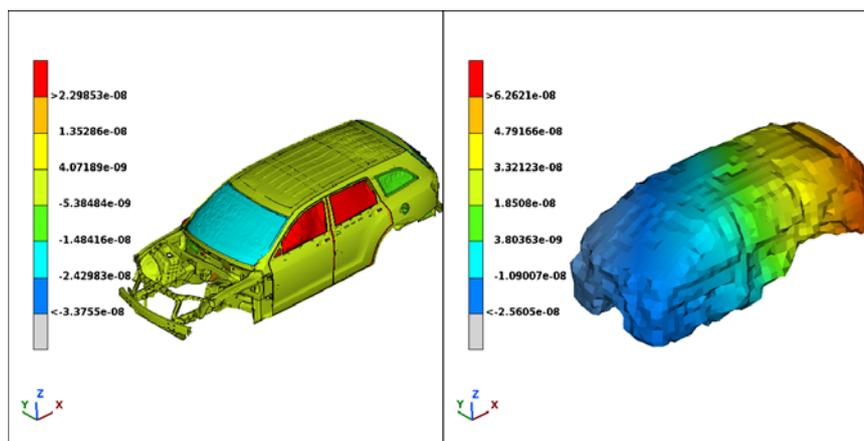

Figure 21 – Normalised grid participations, panel participations & acoustic pressure

Mechanical & Sound Intensity

META provides the option to calculate and load Mechanical & Sound intensity for a Nastran SOL111 analysis, provided that FORCE & DISPLACEMENT results are output in the op2 file (case control commands FORCE and DISPLACEMENT should be included in the Nastran header). These results comprise an indication of the energy flow through the structure or through the fluid.
Figure 22 displays as vector plots the mechanical intensity throughout the Windshield at 50 Hz and the sound intensity through the cabin.
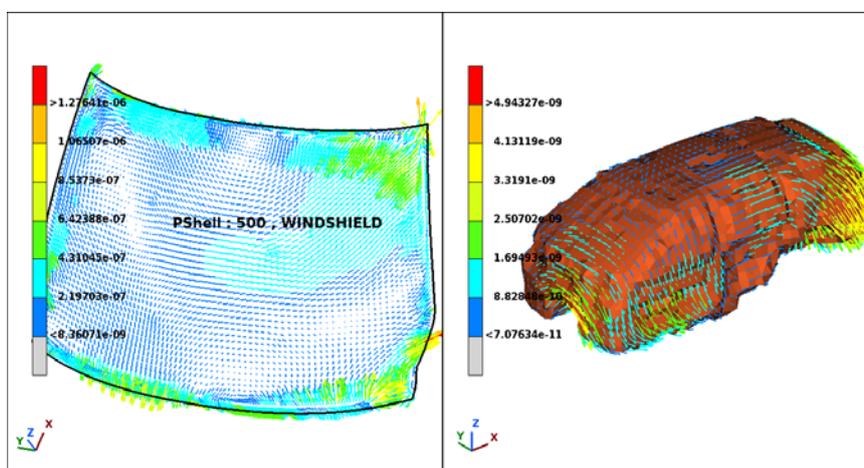Time required for calculating and loading intensity results for one frequency: 2 sec.

Figure 22 – Mechanical & Sound intensity results as a vector plot

4. MODEL REDUCTION BY MODAL MODELING

META can contribute to NVH analysis not only through plane post-processing but also by supporting model reduction, a technique often used to limit the solving turnaround time. One option for model reduction is the substitution of whole subassemblies by their equivalent modal models. These modal models can be created through the Modal Model Builder, embedded within META and can be output in ready-to-run Nastran Bulk files.
The required input for the creation of the modal model is the normal modes results of the FE model. As far as these are available, they are fed to the Modal Model Builder along with the selection of the DOFs that should be included in the modal model.
Figure 23 depicts a typical example for the creation of a modal model: the power-train. The normal modes for the FE model of the power-train have been calculated in Nastran. The DOFs that should be included in the modal model have been connected with PLOTEL elements and these PLOTEL elements are also included in the Nastran Bulk file of the FE model. When META creates the modal model, it also outputs these PLOTEL elements as a visualisation means for the modal model.
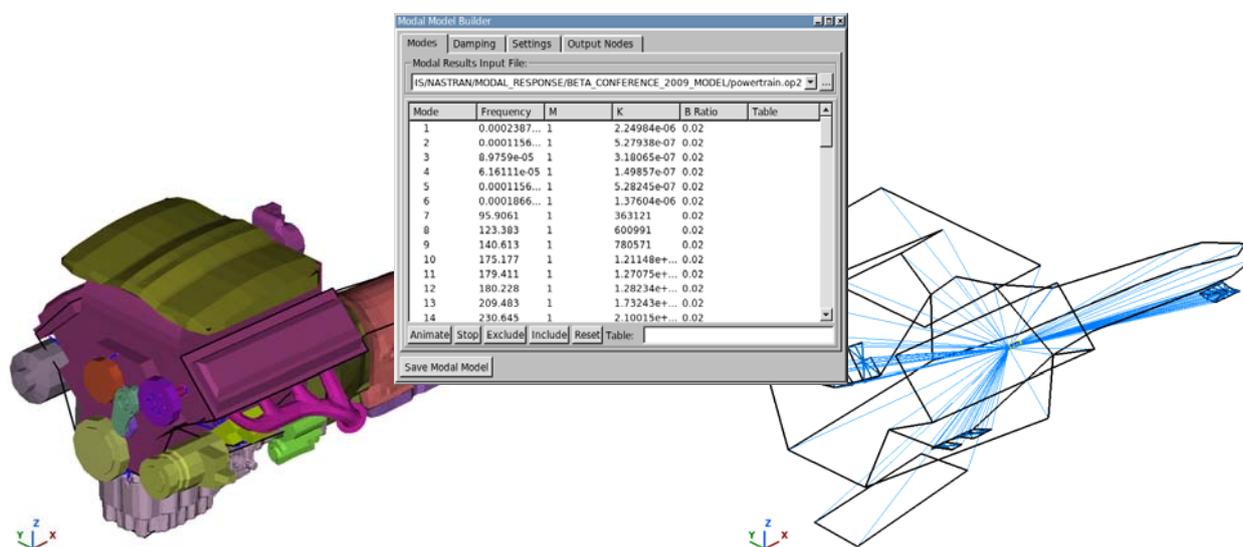

Figure 23 – Creation of the modal model for the power-train in META

5. HANDLING DESIGN OPTIMISATION RESULTS

Design optimisation with Nastran SOL200 is often conducted within the framework of NVH analysis. Beyond the support of standard design optimisation results from Nastran SOL200 in META, one should mention the following advanced capabilities that mainly apply to NVH:
- Direct support of shell thickness results stemming from a design optimisation solution and included in a punch file. These results can be displayed as a contour plot on the FE model (Figure 24).
- Support of sensitivity results from .f06 file. Currently these are supported through a BETA script that reads and outputs them in an ASCII column format file compatible with META. These results can then be loaded as scalar results and displayed as a contour plot on the FE model.
- Support of for design variables, design objective as well as the design responses (DRESP) from a Nastran op2 file. The design variables and objective are standard outputs to the op2 file. However, the design responses can only be output to the op2 file through the use of an MSC "alter" code available from the:
  http ://support.mscsoftware.com/kb/results_kb.cfm ?S_ID=1-80560961
  If the design responses exist in the op2 file, META can read and plot them as curves (Figure 25).
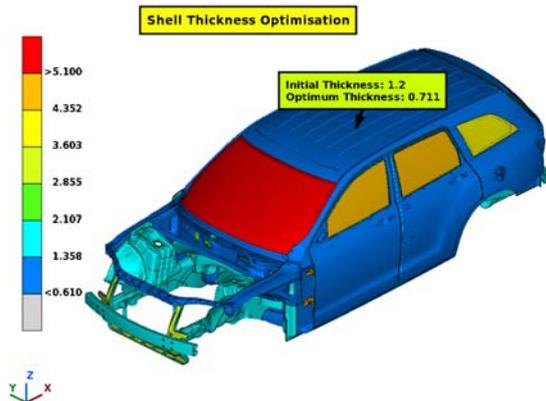
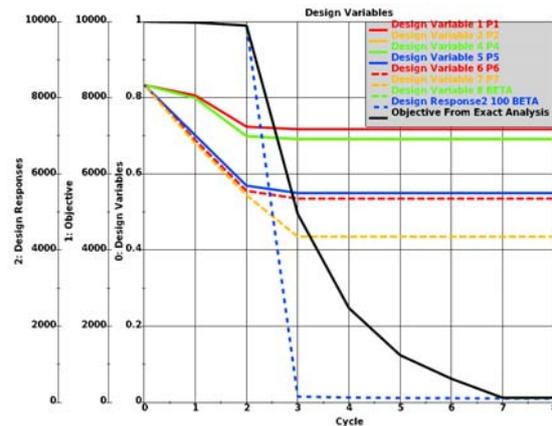Figure 24 – Shell thickness results from design optimisation analysis

Figure 25 – Design variables, responses and objectives

6. CONCLUSIONS

Throughout this paper, a condensed presentation of META capabilities, facilitating NVH post processing, has been attempted. It has been shown that META constitutes a complete suite which does not simply cover most NVH analysis tasks but it also advances the whole process through its following key aspects:

- Outstanding performance for graphics and calculations, as well as optimised memory management and robustness contribute to overcoming constraints emerging due to vast amount of data are created and need to be processed. This results in considerable time-savings.
- Unique automation capabilities through sessions and scripts that enable the streamlining of complicated tasks, speed up post-processing and help users avoid the tedious repetitive actions.
- A complete tool for creating html or pptx reports.
- A tool for the calculation of modal responses which has been verified for its accuracy against the respective results originally output by Nastran. Its main distinctive advantages can be summarised to: its remarkable performance, the easy-to-use interface and the flexibility that offers for the definition of entities which can greatly assist "what-if" studies. An acoustic coupling module is also available and its results are very well correlating with couplings performed by either Nastran or Akusmod.
- A modal model builder for the creation of ready-to-run reduced models.
- A tool for modes correlation.
- Other advanced tools and features, oriented to NVH analysis, such as the calculation of intensity and the support of design optimisation results provide better insight to the model.

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