The 3rd International Conference on
"Computational Mechanics
and Virtual Engineering"
COMEC 2009
29 – 30 OCTOBER 2009, Brasov, Romania

# BREAKTHROUGH TECHNOLOGIES FOR VIRTUAL PROTOTYPING IN THE PRODUCT CREATION PROCESS OF AUTOMOTIVE STRUCTURES

**H. Van Der Auweraer[1], C. Irimia[2], M. Grovu[2]**
[1] LMS International, Leuven, BELGIUM, www.lmsintl.com
[2] LMS ROM, Brasov, ROMANIA, www.lmsintl.com

***Abstract**: The pressures on product innovation and at the same time product customization and cost control are the key drivers for today's vehicle development process. The requirement to develop multiple innovative body variants for each new vehicle platform while shortening the overall time-to-market, puts body development on the critical path in the vehicle development process. This paper discusses a number of new technologies that support such approach in relation to NVH . Morphing the FE mesh of a predecessor model enables the analyst to formulate design recommendations in the concept phase. Model reduction techniques shorten calculation time, enabling more modifications to be evaluated. A first approach is based on a modal projection of the modifications. The second one is based on wave-based substructuring and allows implementing large modifications in a very efficient way. A process is presented and illustrated using industrial examples.*

***Key words**: virtual prototyping, computer aided engineering, concept modelling*

## 1. INTRODUCTION

All industrial sectors are confronted with the conflicting challenges to design better products in a shorter time, and this at a lower product, production and design cost. Globalization of markets as well as providers, increasing consumer awareness and more and more strict regulations on environmental and safety impact ("sustainable products") put the industry competitiveness under large pressure. This requires rethinking the way the design issue is addressed, leading to major innovations in the design process.

As an illustration, the case of vehicle body design will be discussed.

Automotive companies are launching new variants (and redesigning existing models) at an unprecedented pace. Since the vast majority of these vehicles are built on common platforms, body engineering is nearly always on the critical path of the vehicle development process. Functional performances such as crash, structural rigidity, and production feasibility are addressed early in the development process with computer simulation. But attributes as interior acoustics, harshness and vibration comfort pose major challenges for being optimized as part of the core digital development process, due to the size and complexity of involved FE models. As a consequence these are traditionally only considered close to the availability of prototypes. Performance issues discovered at this late stage will lead to additional design cycles together with costly modifications.

To iterate faster to the final design not only requires doing a better optimization job in each design iteration, reducing their total number [1]. Even more important to get more problems solved earlier in the process, is to come up with a vehicle concept that tackles many of the functional performance issues already "by design" (Figure 1).

For the body NVH (noise, vibration, harshness) engineer this raises several practical questions such as:

- How to evaluate NVH performance of a concept design (pre-CAD)?
- Where to get realistic body loads before they can be measured?
- What to do if different attributes lead to conflicting requirements?

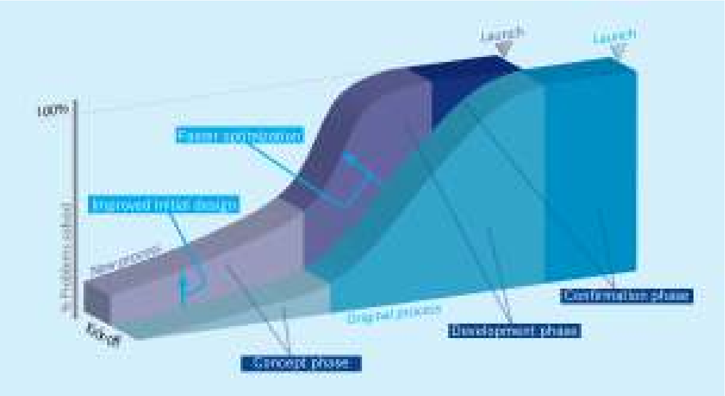

**Figure 1:** Total vehicle development time can be compressed by refining the design in the concept phase and by performing fewer and faster design iterations

Research on these questions has led to several new approaches. Evaluating these new methods in real life vehicle development projects has allowed not only to validate them, but also to work out solutions that are practical.

## 2. CONCEPT PHASE MODELLING

The basic design choices made in the concept phase have a major impact on the functional performance characteristics of the final vehicle. This is not only the case for powertrain mounting layout and the suspension concept, but also for the body. The layout of the body structure contributes a lot to crashworthiness and pedestrian safety but also to ride comfort and its (in)sensitivity to vibrations coming from the powertrain and the tire-road interaction.

In the concept phase no CAD data are available in principle, preventing the use of FE based analyses. In practice, only very few development projects start really from scratch and development is more an evolutionary process. Most new models are based on well-proven predecessors for which detailed FE models for all attributes are already available. These models are very reliable as they can be updated using measurement data on actual production vehicles.

### 2.1 Concept Analysis based on Morphing

The idea behind mesh morphing is that a mesh of a new design can be derived from the existing FE mesh of the old design, based on new styling information and without the need for the actual CAD. It involves moving nodes of the existing model such that the morphed model approximates the new styling data. The required styling information includes surface data describing the outer shape, and line data describing the most important feature lines such as body openings, wheel arch, closures (bonnet, doors, tailgate, trunk lid), glazing, belt line, A-, B-, C- and D-pillars (if available).

Although this is not a requirement for successful morphing, the original FE model should by preference be as similar as possible to the new styling data. The application of morphing becomes more efficient as the differences between the original and new styling remain limited. The morphing operation is not done directly on the existing FE mesh, but via an intermediate “control block” model. This process is illustrated in Figure 2. It involves three major steps [2]:

**Step 1**: **definition of the original control blocks**. Each control block represents a volume that envelops a small part of the existing FE mesh. By linking the location of the FE nodes inside each control block to the location of the corners of the control block, morphing operations applied to the blocks will automatically define the geometry of the morphed FE model. The original control blocks should follow the outer shape of the original FE model as close as possible. In addition, the original control blocks should contain all major feature lines that are present in the new styling data.

**Step 2: creating the deformed control blocks.** Morphing the original control block mesh towards the new styling data creates the deformed control blocks. Not only the outer surfaces but also all major feature lines need to be aligned (possibly iteratively) to the new styling information.

**Step 3: morphing the FE mesh.** Once the deformed control blocks are created, the predecessor FE model can be morphed to fit the new styling data. Some quality checks have to be done on the morphed model, for example

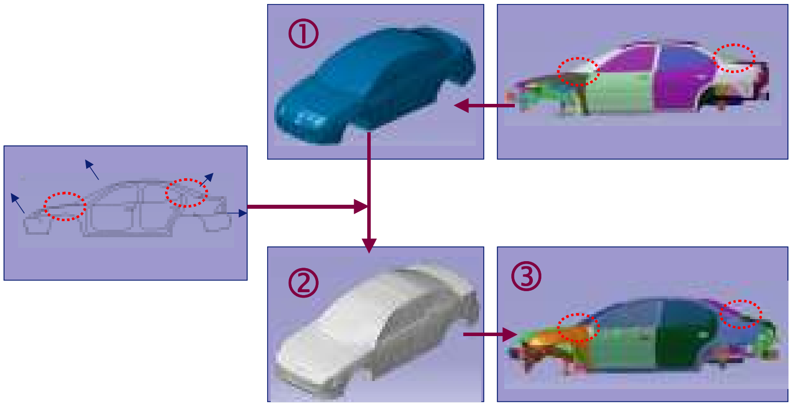

**Figure 2:** Morphing process using the "control block" approach

regarding element quality, mesh smoothness, identification of components that should not be morphed (e.g. internal components like seats or the steering system), proportions of cross-sections, stiffness properties of connections etc. By using the concept of original and deformed control blocks, different types of models (structural and acoustic model) can be morphed separately to the same target styling. Figure 3 shows the original and morphed body mesh for a wheel base variation; Figure 4 assesses the effect on the NVH performance by a body noise transfer function. [3]

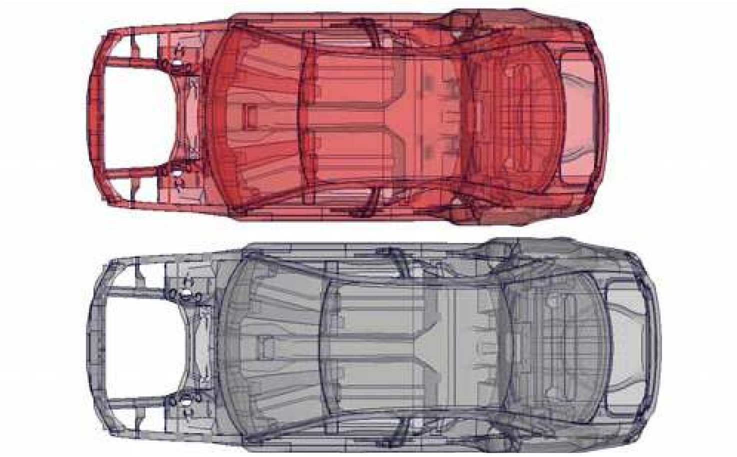

**Figure 3:** Wheel base variations using morphing technology

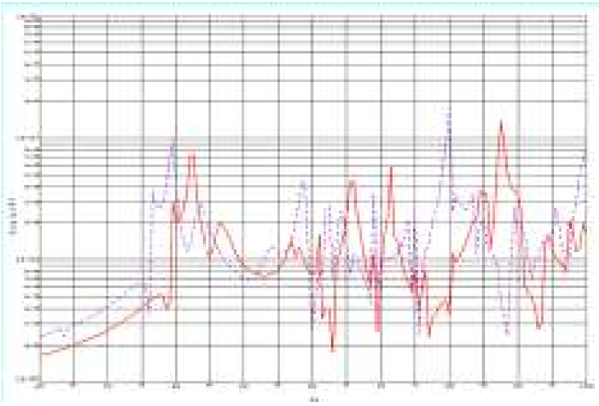

**Figure 4:** Effect of wheel base increase on body noise transfer function

## 2.2 Concept Analysis using Equivalent Beam Models

A second approach is based on a beam-approximation of the structural behaviour. The target frequencies of the first global modes of a body-in-white (BIW) determine to a large extent the properties (e.g. cross section and shell thickness) of the beam-like elements of the body and their connections. Defining these properties is hence one of the first tasks in the concept phase.

The beam concept analysis [4] starts from a structural FE model of a previous generation vehicle, adapted to the new styling using morphing. A network of beam elements is then defined on top of the body FE model (Figure 5). Beams and connections are such that they do not introduce any perturbation on the BIW. As a second step, a modal based method is used to reduce the original BIW FE model, keeping only a limited set of nodes.

This concept model is used to calculate the modal properties of the body and to carry out sensitivity and modification studies in a similar way as is done with experimental modal models (changing e.g. the properties of the added FE beam and connection elements). Sensitivity analysis for instance can identify the beam sections for which an increase in bending stiffness would have the most impact on the frequency of a given global mode. Typical results of such an analysis are shown in Figure 6.

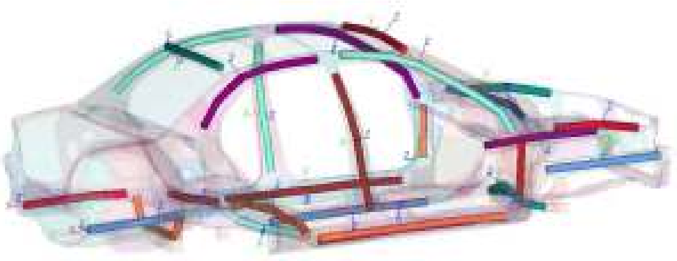

**Figure 5:** Layout of the modifier beams

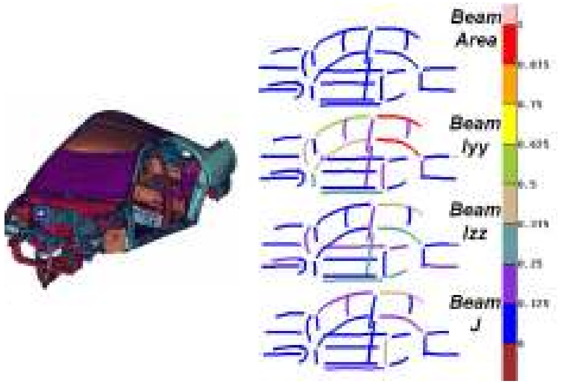

**Figure 6***:*Frequency sensitivity of a global mode to the bending stiffness of beam sections

Since the reduced model runs very fast, numerous modification as well as parameterized optimization analyses can be performed in a limited time.

## 3. Speeding Up Design Iterations

Being able to verify whether design targets are met using virtual prototypes is just one thing. The real challenge is to use these virtual prototypes to evaluate possible countermeasures or design alternatives in case targets are not met. This requires the calculation of many variants, which is not feasible in the short time available between two design iterations if a single run would already take many hours or even a day.

One approach is the use of parallel or Grid computing architectures to reduce the total evaluation time [8] or to use special solvers or calculation procedures. Examples are the use of iterative solvers or an Acoustic Transfer Vector (ATV) approach for speeding up vibro-acoustic calculations [9].

The alternative is to speed up the calculation by doing a smart reduction of model sizes. A compact model will then represent body parts that have no impact on the problem, while the areas the analysis engineer wants to focus on will be modelled in adequate detail. Different approaches exist depending on the type of problem. But an asset to their successful application is that first a proper assessment and localization is performed on the root causes of the NVH problem so that the areas of interest can be clearly identified.

## 3.1 Weak spot identification

In order to get a detailed understanding of the mechanism behind problems and quickly propose design fixes, the analysis results of the different attributes can be post-processed using weak spot detection tools. For NVH powerful contribution analysis methods are used such as [10]:

- Panel contribution analysis indicating which panel is radiating the noise.
- Path contribution indicating e.g. which suspension connection point is dominant for the structure borne noise transfer.
- In the lower frequency range, modal contribution analysis is used.
- Using test-based loads, geometric response animations at problem frequencies may lead to a detailed understanding of the deformations.

## 3.2 Wave-based substructuring

Wave-based substructuring or WBS [4,11] is a new method, developed to address one of the greatest difficulties in body simulation, creating the structural model of the full body starting from the FE models of individual parts as there are numerous connections between these parts that are often very complex to model, Figure 7 (e.g. the thousands of spot welds in a body and the hard-to-simulate line connections such as the weather stripping around doors and tailgate).

The WBS method expresses the deformation of the coupling interface as a combination of a set of basis deformations called “waves” that are analogous to mode shapes. Connections that are normally defined in terms of the interface degrees of freedom (DOF) are replaced by connections between waves, imposing continuity of the displacements and forces. The number of interface DOFs is reduced from the number of nodal connection DOFs to the number of waves, which substantially reduces the computational workload.

The actual time gains depend mainly on the percentage of the full model that can be reduced. In test cases [4] where a reduced tailgate was connected to a reduced body, representing the connection between both (the weather stripping) by waves, the calculation time of the trimmed body modes could be reduced by a factor of 1,100. In another case where the cowl top was represented in full FE and the rest of the body was represented by a reduced model, calculation times were 52 times lower. These numbers could be further improved by reducing the number of connection waves, which would however impact modelling accuracy.  A good trade-off between calculation speed and accuracy has to be found depending on the application.

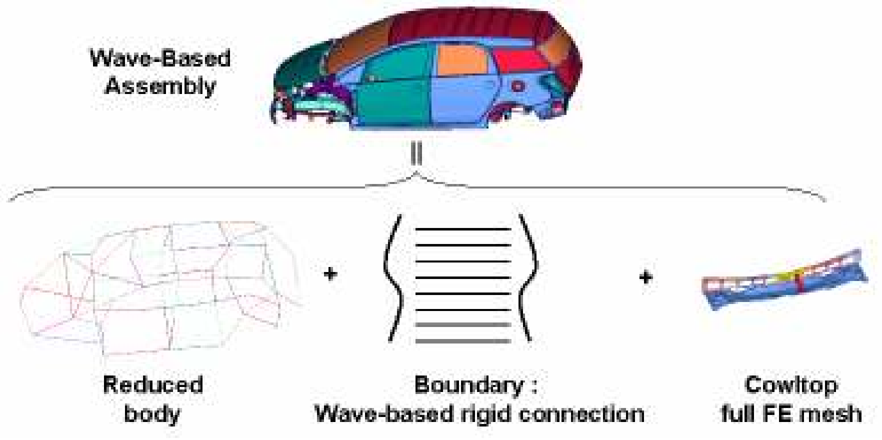

**Figure 7**: Concept of wave-based substructuring (WBS)

This WBS approach opens many new possibilities to evaluate the impact of local design modifications on system performance, for example the effect of number and size of beads in a floor panel on interior acoustics, the size and position of subframe holes on the transmission of engine vibrations to the drivers seat or position and number of spot welds on fatigue life.

### 3.3 Modal Projection Approach

The second approach, modal projection of design modifications, is used for the optimization of vehicle NVH performance for small modifications, typically during the refinement phase of the development cycle. Design parameters, such as thicknesses or material properties of components such as subframes or body panels, as well as local geometry modifications can be considered. The body areas whose modification is expected to have the most impact on NVH are identified from a weak spot detection analysis and a set of nominal modifications is defined. Each nominal modification is projected in the modal domain and its effect on the system response can be quickly determined. Scaling factors are assigned to each modification and can be used as design parameters in an automated optimization process.

## 4. Conclusion

The paper uses the example of vehicle body engineering to give an overview of key innovative virtual testing approaches that answer today's product design challenges worldwide. It covers concept level design, methods to speed up design iterations, techniques to enable accurate response predictions for actual loading conditions. These methods offer new opportunities for multi-disciplinary optimization and design for six-sigma in the area of functional performance engineering. They make it viable to turn the vision about "analysis leads design" into a practical engineering process.

## REFERENCES

[1]Shiozaki H., Kamada Y., Kurita S., Goossens S., Van Herbruggen J., Cibrario V., Poppelaars L., "CAE based vehicle development to reduce development time", Proceedings of the 2005 JSAE Annual Congress, paper 20055472.

[2]Bosmans I., Brughmans M., Brizzi P., Shiozaki H., Yanase J., "Application of morphing in concept phase of vehicle development", Proceedings of the 2005 JSAE Annual Congress, paper 20055475.

[3]Van der Auweraer H., Van Langenhove T., Brughmans M., Bosmans I., El Masri N., Donders S., "Application of mesh morphing technology in the concept phase of vehicle development", Int. J. Vehicle Design, Vol. 43, Nos. 1-4, 2007, pp. 281-305

[4]Hadjit R., Brughmans M., Shiozaki H., "Application of fast body optimization procedures to shorten car development cycles", Proceedings of the 2005 JSAE Annual Congress, paper 20055473.

[5]Lopez I., Roozen N.B., Nijmeijer H., Blom R.E.A., "Modelling the vibrations of a rotating tyre: a modal approach", Proc. Forum Acusticum 2005, Budapest, Hungary, Aug.30-Sep. 2, 2005.

[6]Gagliano Ch., Martin A., Cox J., Clavin K., Gérard F., Michiels K.; "A hybrid full vehicle model for structure borne road noise prediction", Proceedings of the 2005 SAE Noise & Vibration Conference, paper 2005-01-2467.

[7]Bäcker M., Langthaler Th., Olbrich M., Oppermann H.; "The hybrid road approach for durability loads prediction", SAE paper 2005-01-0628.

[8]Tournour M., Rossion J.P., Bricteux L., McCulloch C., "Getting Useful FEM and BEM Vibro-Acoustic Solutions Faster, Using New Solution Methodologies", Proc. ISMA 2002, Leuven, Belgium, Sept. 16-18, 2002.

[9]Gerard F., Tournour M., El-Masri N., Cremers L., Felice M., Selmane A., "Numerical Modeling of Engine Noise Radiation Through the Use of Acoustic Transfer Vectors - A Case Study", Proc. and exposition report, SAE Noise and Vibration Conference, Traverse City, Michigan, USA, April 30-May 3, 2001.

[10]Van der Auweraer H., Tournour M., Wyckaert K., De Langhe K., "Vibro-Acoustic CAE from an Industrial Application Perspective", SAE paper SIAT2005-0157, Proc. SIAT 2005 conference, Pune, India, Jan. 19, 2005.

[11]Donders S.; Hadjit R., Cuppens K., Brughmans M., Desmet W., "A Wave-Based Substructuring Approach for Faster Vehicle Assembly Predictions", Proc. NOVEM 2005, Saint-Raphaël, France, April 18-21, 2005.

[12]Donders S., Van de Peer J.; Dom S., Van der Auweraer H., Vandepitte D., "Parameter Uncertainty and Variability in the Structural Dynamics Modelling Process", Proc. IMAC XXII, Dearborn, MI, USA, Jan.26-29, 2004.