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Procedia Engineering 49 (2012) 287 – 293

Procedia Engineering

www.elsevier.com/locate/procedia

Evolving Energy-IEF International Energy Congress (IEF-IEC2012)

# Vehicle concept modeling: A new technology for structures weight reduction

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**Elsevier use only:** Revised 23rd July 2012; accepted 24th July 2012

**Abstract**

The lightening of the vehicle body structure generally aggravates the noise vibration and harshness (NVH) and the crash performances of the vehicle. The development and application of the vehicle advanced computer aided engineering (CAE) allowed the vehicle designers to considerably reduce the weight and improve the structural performance of the body. However, the current advanced (detailed) CAE model can only be available in the late design phase of the vehicle when only minor changes of the structure is feasible. Unlike the detailed CAE model, which requires all detailed design, the concept CAE model can be created without any need to the detailed CAD data and it can be created in the early (concept) design phase. Accordingly, in this paper, a concept modeling method is presented for a sedan car. This model represents the major structural dynamic characteristics of the body and enables the designers to optimize the structure in terms of the performances and mass in early design phase. The detailed CAE model of the body-in-white (BIW) of vehicle is reduced to a beam elements concept-structure so that the concept structure has similar structural dynamics behavior with the corresponding test data. The developed CAE concept model demonstrates a robust method to enhance the NVH and crash performances in early stage of design. The proposed method can be used to effectively predict and optimize the vehicle body structure and support body lightweighting design process. The reduction of BIW mass will ultimately reduce fuel consumption leading to energy efficiency and reduced pollution.



Keywords: Lighweighting; NVH; CAE; Concept modelling; Structural dynamics

## 1. Introduction

The present highly competitive automobile market demands the cost-effective and lightweight [9, 10] vehicle design in short market periods. It is therefore crucial to predict and improve the car performance in various conflicting areas such as NVH and safety in the earliest stage of design. The CAE method has been a great tool for automotive engineers to improve the NVH or safety of the vehicle before making any physical car [1, 2, 4]. The models that are developed by this method are called CAE detailed models or CAE advanced models. Such CAE models (detailed or advanced models) can only be created with all design details as well as all accurate geometry and CAD data of the body [1, 2]. Such detailed CAD and design data are usually not available in early design phase. Therefore, in the late design phase, with more constrained design, no major changes can be done. The detailed CAE models can mainly be useful for minor modifications of the body. Furthermore, the

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 doi:10.1016/j.proeng.2012.10.139

detailed CAE models have large data sizes and each computation run for a whole trimmed body may take, higher computation time up to several hours. Consequently, because of such limitations for the detailed CAE models which are currently used in the industry, some attentions have been devoted to the development of the concept CAE models. Unlike the detailed CAE models, the concept models have relatively simple structures and they do not need complete detailed CAD data. This makes possible to provide low cost and fast solutions for improving the NVH or crashworthiness of the car in early design phase.

A concept CAE model is generally developed by beam elements and sometimes a combination of beam and shell elements [11, 12]. The concept model can be created concurrent with CAD data or based on the predecessor FE model. The development method for a concept CAE model is also related to its application. Some of the simplifications that needed for developing a crash analysis concept model may be different for developing a NVH concept model. Most of the vehicle NVH issues are linked to the BIW structural dynamics. The BIW and its platform can be modified mainly in the early design stage when the major modifications are more feasible. Automotive designers have various sub-targets for the BIW for improving the structural dynamics and therefore NVH quality of the BIW. Accordingly, the focus of this study is to develop a concept model for characterizing the structural dynamics and therefore NVH quality of the vehicle BIW [1, 4].

In this paper, a concept CAE model is developed for a sedan car BIW. The dimensions and geometries of the beam members are obtained from the predecessor CAE detailed model, and then refined and represented by equivalent standard beam elements. Structural dynamics of the BIW is characterized by obtaining the fundamental vibration modes via the experimental modal analysis using LMS software [7]. The developed concept model is then tuned to have same fundamental resonant frequencies with its corresponding test data. This has been done by using optimization tools in Nastran software. The results show that the developed simple cross section concept model has a good consistency with its corresponding test results. The developed concept model can be a good tool to perform upfront NVH analysis and optimization.

## 2. Method

The concept model is created using analytical method of section reduction and predecessor model of vehicle. The created concept model is cross-validated with experimental methodology of modal analysis of BIW.

### *2.1. Experiment*

The analytical method is validated by experimental analysis using LMS measurement system for main global frequency mode comparison with modal structure analysis. The experimentation involves positioning of test BIW on air mounts with equivalent pressures and force input is given to single point to demonstrate dynamic conditions of free vibration. The test object BIW is tested for frequency range of 0-200Hz. It helps analyzing global vibration frequency modes in form of frequency response function captured using LMS system modal analysis. However first five significant global vibration mode of body are identified in range of 0-60 Hz [5, 13].

The experiment (Fig. 1) involved calibration of input and output signals from at 133 node points on automotive body using standard accelerometers. These accelerometers provide signal inputs of three directions of body vibration to LMS scadas connected via signal transfer cables. The signal outputs from body to accelerometers (i.e. inputs to LMS system) are superimposed or individually analysed using LMS system. These signals help plotting FRF's for various directions of body vibrations to achieve body vibration mode shapes using LMS system. Fig 2 shows focused significant area of Frequency response functions i.e. FRF acquired from LMS modal analysis of BIW for actual global vibration data and CAE analysis using HYPERWORKS and NASTRAN [6, 7] as analysis tools.

Fig 1: Experimental modal testing of the BIW

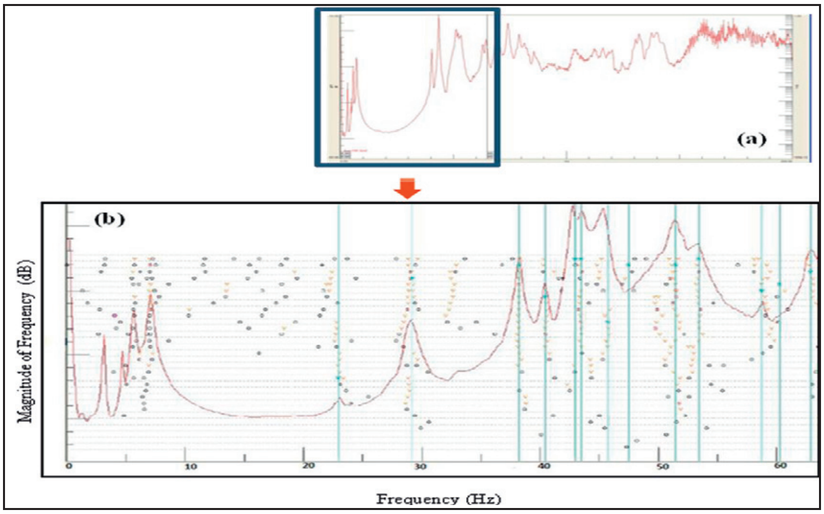


Fig 2: Output of LMS modal analysis, Frequency response function (a) for frequencies 0-200 Hz (b) For frequencies 0-60Hz

The frequency response functions from modal analysis using LMS system and Hypermesh and Nastran free body vibration analysis are compared. They provide significant body vibration peaks to identify global vibration frequencies of vehicle chassis and mode shapes. The mode shape similarities are cross verified by calculating mode assurance criteria.

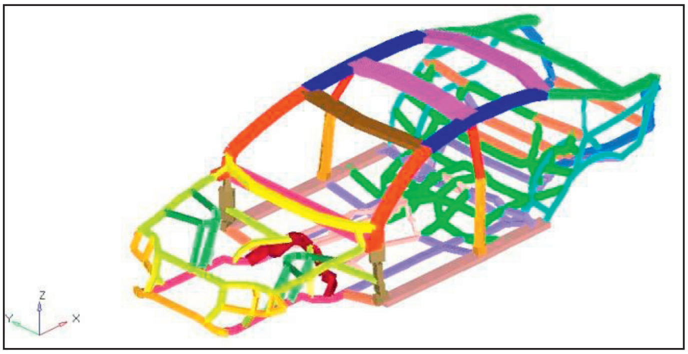

Fig 3: The developed concept beam model.

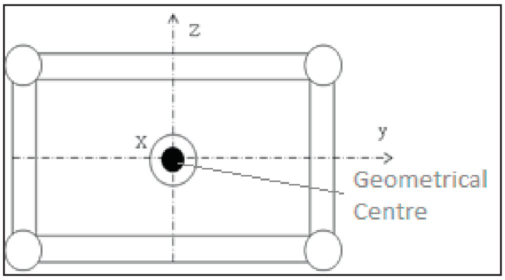


Fig 4: Schematic representation of Beam end-section

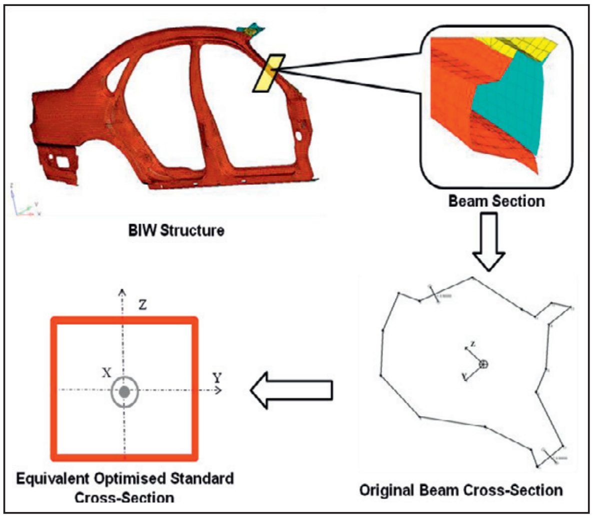


Fig 5: Practical implementation of method

*2.2. Analytical*

Analytical method provides approach towards reduction of detailed CAE model into reduced beam model (Fig. 3). This method allows variation in mainframe of vehicle structure (for example from sedan to hatchback with similar platform) and analysis of its vibration effects on complete structure. The analytical method provides specified insights about various vehicle component reduction based on their structure and cross section.

Primary structural members of vehicle chassis such as A, B, C pillar, Main floor members etc are in form of columns and beams. The method can be practically implemented, by selecting column or beam cross sections from detailed CAE model and reducing it to standard cross section. Initially detailed CAE model is analysed with Hypermesh. The detailed geometrical cross section of vehicle components are selected to analyse principal moment of inertia, Geometrical centre (i.e. Centroid) and angle of rotation from local to principal axis. These properties are implemented while defining dimensions of equivalent standard cross section. The centroid of primary structural elements is treated as geometrical centre for equivalent reduced beam model and values of moment of inertia in directional of local axes as shown in

Fig 5: Practical implementation of method

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After analyzing the properties of detailed cross section, using Hypermesh and Nastran superelement an equivalent standard rectangular cross section is created and connected to each other. All the beam sections can be reduced along geometrical centre to equivalent standard beam end-section having constant mass, stiffness and inertia properties as shown in.

A procedure for achieving this standard cross section is as follows,

1. Cut nodes are selected for identification of section geometry and detailed cross section. Intersection planes are defined at these cut nodes.
2. Estimation of geometrical centre, principal moment of inertia, orientation of local axis from principal axis are calculated using Hypermesh as shown in Fig 6

3. This data is used to create equivalent standard beam section by Hypermesh and Nastran. As values of principal moment of inertia are geometric centre used. There is no need of implementing angle of rotation between local and principal axes of geometry.

4. These geometrical centres are connected to surrounding mesh by interpolation relations using Nastran (Super element RBE3) between geometric centres & cut nodes. They are defined for particular node group and for the nodes under set of shell elements at which intersection planes were defined [6, 7].

Vehicle structure panels are secondary members. They have significant impact of modes and frequency of vehicle structure vibration. They are reduced using similar method along with analysis of mass distribution along main members in floor and roof of BIW. Joints are analysed and implemented by similar method and varying cross sections. The reduced vehicle structure is analysed for free vibration with help of Altair Hyperworks and Nastran. The analysis provides global modal vibration frequencies of structure which are cross-validated using experimental method.

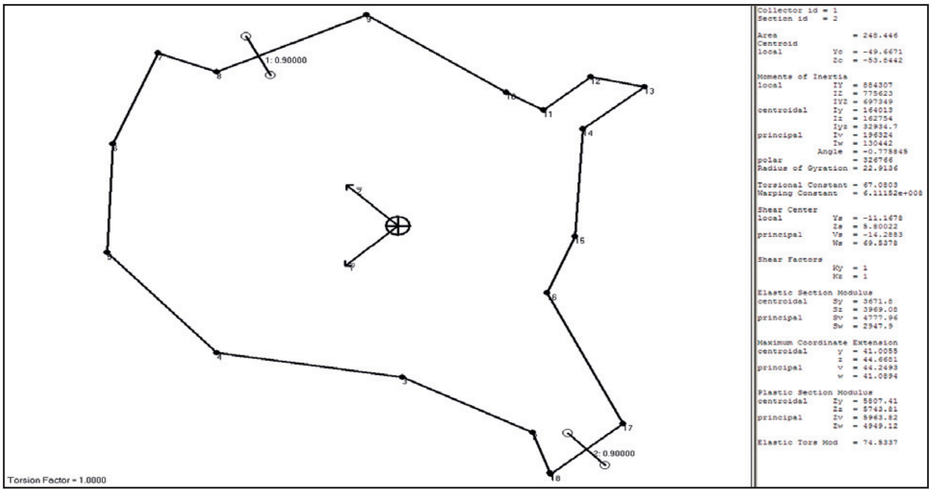


Fig 6: Hypermesh cross section properties

## 3. Result

The structural dynamic analyses results from the concept model are compared with that of the modal test results (Table 1). The main resonant frequencies and their corresponding mode shapes are compared between the simulation and experiment. Taking above-mentioned materials into consideration, the natural frequencies differences and (Modal Assurance Criteria) MAC of the concept and advanced models are computed to validate the developed NVH concept model [5, 13]. The MAC index between similar modes of two models is calculated by the below equation, in which $\Phi_E$ and $\Phi_C$ are the Matrix of Eigen vectors for the experimental results and concept model, respectively, and superscript T denotes the transpose of a vector. The Eigen vectors are constructed by using main structure nodes in the test and corresponding nodes in the concept model.

$$MAC_{AE,C}\Big|_k = \frac{(\{\Phi_{AE}\}_k^T \{\Phi_C\}_k)^2}{(\{\Phi_{AE}\}_k^T \{\Phi_{AE}\}_k \{\Phi_C\}_k^T \{\Phi_C\}_k)} \quad (1)$$

A MAC value equal to unity indicates a 100% similarity between the vibration mode shape obtained from the simulation and that of obtained from the experiment. The MAC values, in the Table 1, for the five modes are found to be nearly 0.7 (Table 1), which indicate a good consistency between the modes of the developed model and those of the test data.

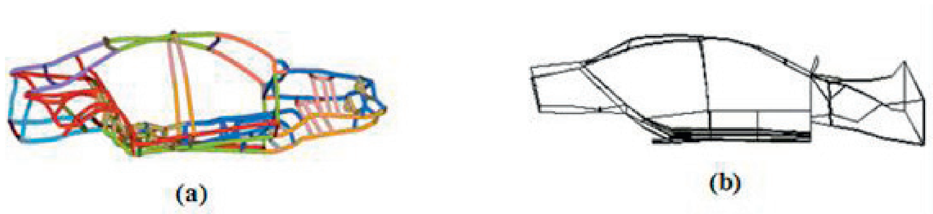


Fig. 7. Comparison of the BIW concept model torsion mode (a) with the torsion mode from the modal testing (b)

Table 1: Comparison between the structural modal analysis data and the final conceptual FE model in terms of global frequencies and modal shapes

| Mode shape | Frequency (Hz) | | Δ(Hz) | MAC |
|---|---|---|---|---|
| | Experimental result | Reduced model | | |
| Floor Resonance | 40.358 | 42.98 | 2.62 | 0.74 |
| 1st Torsion | 43.495 | 45.04 | 1.55 | 0.79 |
| 1st Bending | 47.351 | 49.26 | 1.91 | 0.76 |
| 2nd Bending | 53.415 | 55.08 | 1.67 | 0.74 |
| 2nd Torsion | 63.416 | 64.30 | 0.89 | 0.67 |

The torsion mode shape of the developed concept model is compared with the torsion mode shape obtained from test data (Fig. 7). A good consistency is seen between the test and simulation. We can see from the obtained results, shown in the Table 1 and Fig. 7, that the developed concept mode is a good model to use for predicting the major (global) issues about the structural dynamics of the body in early design phase when the detailed model is not available.

## 4. Conclusions

The lightening of the vehicle body structure generally aggravates the NVH and the crash performances of the vehicle. The development and application of the vehicle advanced CAE allowed the vehicle designers to considerably reduce the weight and improve the structural performance of the body. However, the current detailed CAE model can only be available in the late design phase of the vehicle when only minor changes of the structure are feasible. Unlike the detailed CAE model, which requires all detailed design data, the concept CAE model can be created without any need to the detailed CAD data and it can be created in the early (concept) design phase. The developed concept model, here, represents the major structural dynamic characteristics of the body and enables the designers to optimize the structure in terms of the mass and performances in early design phase. The created concept model is then tuned to have same structural dynamic responses (fundamental resonant frequencies) with its corresponding test data. This has been done by using optimization tools in Nastran software. The results show that the developed concept model has a good consistency with its corresponding test results. Hence the developed method presents a good tool to reduce the vehicle structure weight and optimize NVH performances of the structure. In addition to the weight reduction, the presented method significantly saves the CAE modelling and computational time for the vehicle structure. The reduction of the structure mass will ultimately reduce the fuel consumption leading to energy efficiency and reduced pollution.

## Acknowledgements

The authors are grateful for the support of the AutoCRC to conduct this study.

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