"MSC/NVH_Manager Helps Chrysler Make Quieter Vibration-free Vehicles"

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Abstract

A new software concept, the MSC/NVH_Manager, is being used at Chrysler to improve the Noise, Vibration, and Harshness (NVH) quality of future vehicles. This Noise and Vibration simulation interface is focused specifically on the needs of the automotive market. The MSC/NVH_Manager makes it easier for Chrysler Engineers to evaluate the vibration characteristics of their designs while they are still on paper and before resources are committed to build prototypes. The software interface provides a "point and click" capability to build a complete vehicle for the study of structure borne NVH. This paper will discuss the features and benefits of the software to Chrysler Corporation and show examples of its usage.

Introduction

Computer Aided Engineering has been evolving rapidly with the introduction of faster and cost effective computer resources. At Chrysler, the need for higher quality, better fuel economy, quicker time to market, and lower product costs have resulted in demand and utilization of increasingly more sophisticated and accurate computer simulations of vehicle performance. These simulations give Chrysler management a tool upon which to base design decisions far in advance of when resource is committed to manufacturing and faster and at much lower cost than prototype build-and-test processes.

MacNeal-Schwendler Corporation recently reorganized into several business units to better serve its simulation software customers using MSC/NASTRAN. The Automotive Group (AG) was formed in 1996 with the goal of emphasizing software solutions that specifically serve the automotive industry. One of the first software products of the AG was the MSC/NVH_Manager, currently used at Chrysler Corporation by each vehicle platform. The MSC/NVH_Manager is the first of the process simulation tools that focus on providing software that can be adapted to a specific customer's established CAE procedures and work within his unique environment (Ref. 1).

The MSC/NVH_Manager provides a complete modeling and simulation environment for Chrysler engineers to predict NVH performance of complete vehicle assemblies subjected to "real world" loads. The full vehicle assembly includes tires, suspension, powertrain, body, and interior acoustic cavity. The load conditions which can be simulated include, 1. road undulations which come through the tires, or 2. combustion forces which come through the engine block. Thus, the entire structure borne noise and vibration path from the tire patch or from the engine cylinders to the driver's ear (where the customer perceives the NVH quality) is simulated.

Previous NVH Simulation Process

The previous method of performing full vehicle NVH analysis at Chrysler required all model building within a single proprietary general purpose finite element builder and visualizer. The process was tedious requiring manual hand coding of kinematics equations used to define suspension motion and a high level of expertise to assure that a quality model was built. As a result of the complexity, some platforms did not perform full vehicle simulation at all, instead opting for component analysis alone based on sub-system modal targets.

Quite sophisticated body structure models were constructed at Chrysler and analyzed for stress and dynamic modal characteristics. Chassis modelers built sophisticated suspension models and provided body dynamic performance requirements for the body structure to manage the forces predicted at interface points (Ref. 3).

Chrysler recognized a need for a system that would allow an entire vehicle to be analyzed as an assembly since the interactions between the body and chassis were known to influence vehicle NVH performance. Exercises to arrive at performance targets for the body and chassis as components, separate from each other, were resulting in best-in-class specifications for both sub-systems which, 1. were not cost competitive and, 2. were not resulting in a best-in-class vehicle when assembled due to unexpected interactions at the vehicle level (Ref. 4).

It was recognized that NVH performance required an optimum matching of the interaction from each sub-system which allowed for trade offs in performance at the component level. These trade offs could only be evaluated with a full vehicle NVH simulation including all component sub-system dynamic interactions. Robert Lutz, Vice-Chairman of Chrysler, stated in a speech to academics, "At Chrysler, I like to think that true *holistic* thinking has played a big - perhaps even a pivotal - role in our company's recent success". This concept of holistic thinking, where a whole system along with its

sub-system interactions are considered together, was demonstrated to also be necessary for the simulation of NVH performance at the vehicle level (Ref. 2).

MSC/NVH_Manager Simulation Process

The MSC/NVH_Manager was conceived from the beginning to empower the automotive NVH engineer with the tool needed to perform NVH simulations of complete vehicle assemblies. The basic modeling strategy of the software is to separate the modeling tasks down into body, suspension, and powertrain sub-systems and then provide for automated assembly. Beyond modeling, the MSC/NVH_Manager provides a complete simulation environment through a graphical user interface which assembles the models, applies the dynamic load condition, submits and monitors jobs for execution, and displays the results. With a model of the complete vehicle, real world loads can be applied and the interactions of all of the sub-systems can be "holistically" evaluated for NVH

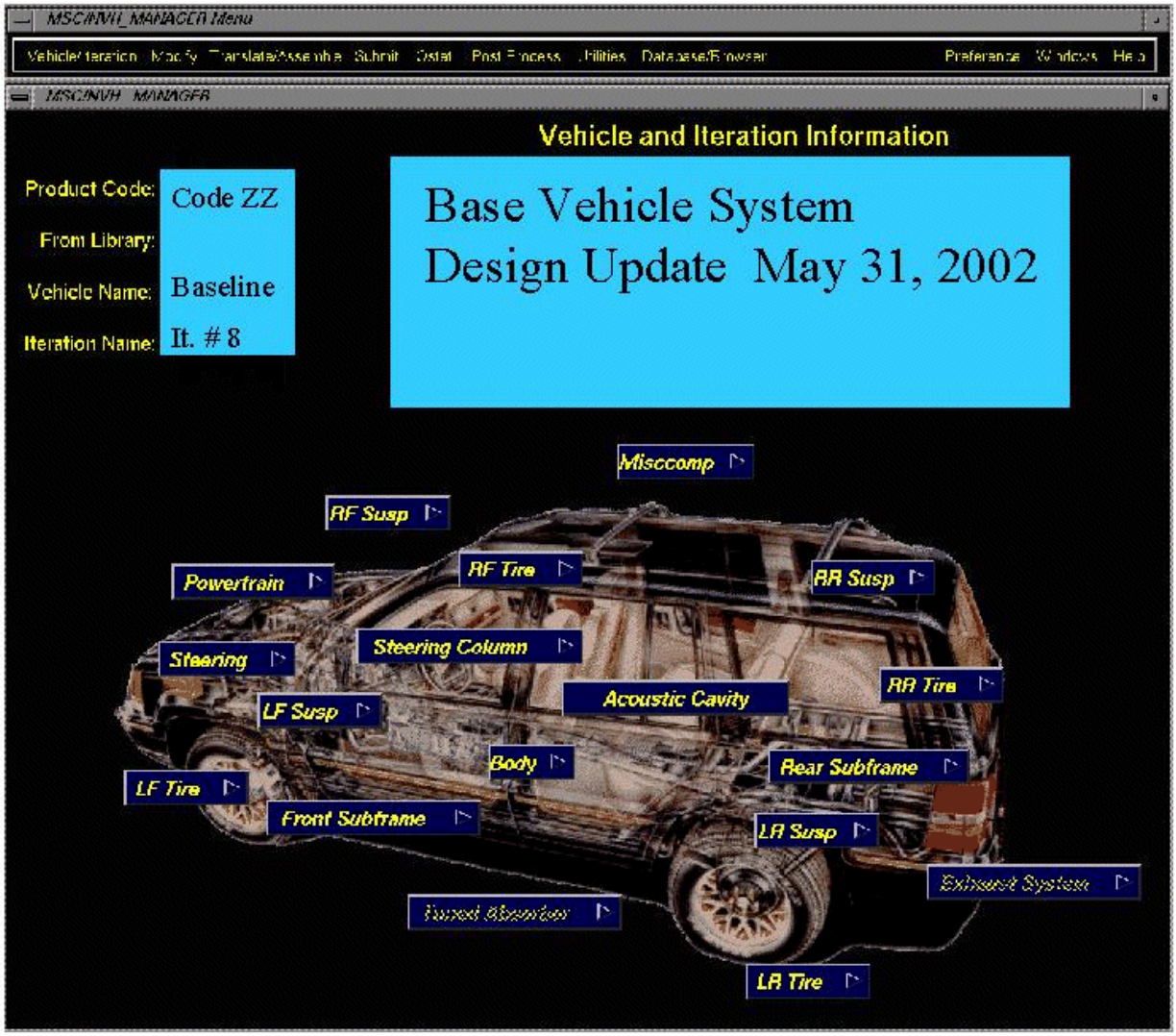

Figure 1: MSC/NVH_Manager Simulation Interface Display

performance.

The foundation of the MSC/NVH_Manager allowing for quick modeling and analysis turn around is the ease of access to the sub-systems which comprise the full vehicle. Figure 1 shows the menu system displayed graphically for the NVH analyst ready to perform a simulation. The buttons shown with sub-system names such as Body, Powertrain, LF Susp, etc. allow point and click access to each of these automotive systems to change design parameters, such as bushing stiffness, orientation, part masses, etc. Each sub-system is modeled using a Template, which is a *pre-engineered* layout of the automotive parts in the sub-system. In the case of suspension sub-systems, it was found that there were only a few configurations of suspensions currently in use at Chrysler so that a separate Template model could be easily made for each vehicle platform. Then the analysts on that platform could enter the design data such as bushing rates and part masses and result in an accurate model.

This concept of the pre-engineered Template for the sub-system has worked well at Chrysler. More experienced vehicle NVH analysts can create kinematic models of generic suspensions, powertrains, axles, etc., verify their accuracy using the MSC/NVH_Manager, then supply them to analysts supporting a new vehicle platform who may be more experienced at modeling body structure. Then the MSC/NVH_Manager provides the interface for platform specific design data to be entered and/or updated. The MSC/NVH_Manager performs data entry checking and issues assembly mis-matching messages so the analysts can detect common modeling errors and correct them before jobs are submitted. Lastly, the full vehicle is assembled and evaluated for NVH performance all within the MSC/NVH_Manager point and click interface.

Idle Vibration Isolation Example

An example application of the MSC/NVH_Manager was to reduce the vibration experienced by a passenger for a common engine loading condition called idle. Idle excitation occurs when the vehicle is at rest and the automatic transmission is in gear, such as when waiting at a traffic light. This vibration, like many NVH problems, can be very annoying to the customer, since the input is very consistent and repeatable, especially for urban drivers who experience it frequently.

The goal was to reduce the vibration to an acceptable reference vibration level measured where the passenger sits. This points out the need for a complete vehicle model which can represent the idle combustion loads applied at the engine, transfer the load through the drive shafts and engine mounts, and excite the body where the passenger experiences the tactile vibration.

An important feature of the MSC/NVH_Manager is that detail can be added as it is needed (and becomes available) during a new vehicle program. The idle NVH problem occurs at low frequency where the powerplant system and other chassis components can be considered to act as rigid inertial bodies. Therefore, only their mass and inertia properties are needed for an accurate analysis of idle conditions. However, a typical unibody structure, will experience its fundamental first bending and torsional resonances in this range of 20 to 30 Hz, thus requiring an FEA model.

Figure 2 shows an example of an assembled kinematic full vehicle model from the MSC/NVH_Manager. It represents a four wheel drive sport utility with unibody structure, solid axle front and rear suspensions, and a north-south powertrain. The model shown is called a Template vehicle where all the sub-systems have been assumed to be rigid inertial bodies. It is used for checking Template accuracy and the reasonableness of suspension and rigid body powerplant modes since these modes occur below the first body resonances. To perform the idle analysis, a detailed model of the body replaces the rigid Template body using an MSC/NVH_Manager "Import" feature. The analyst identifies the

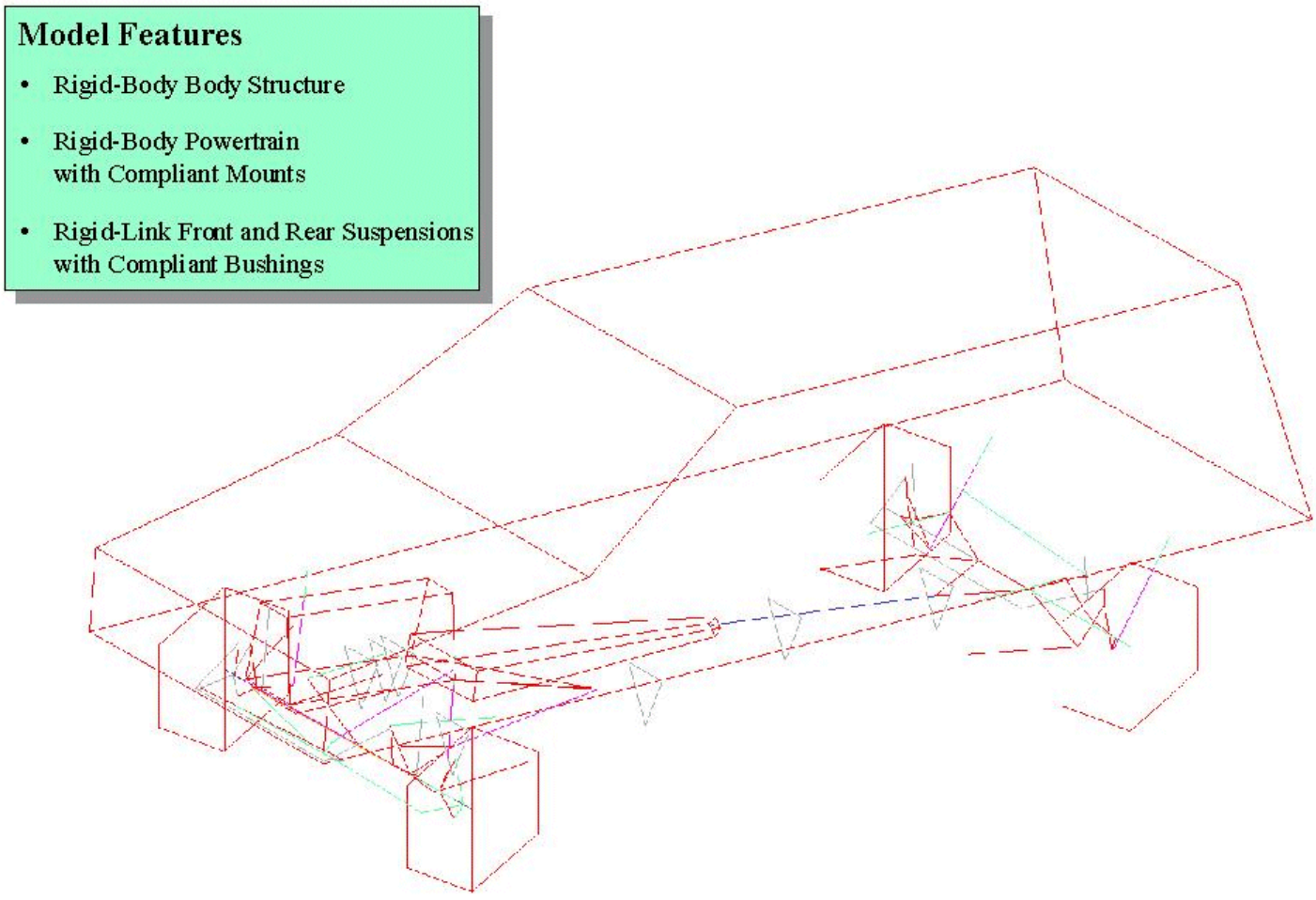

Figure 2: Kinematic Vehicle Model using Rigid Links, Masses, and Compliances

points on the body which attach to the chassis (usually less than 20 points per side), then the MSC/NVH_Manager will perform the substitution automatically and assure that all the chassis attachments are intact.

Several design alternatives were evaluated to reduce idle vibration amplitude. The results are shown in Figure 3, where the change in vibration level as a % of a desired reference amplitude is plotted in a bar chart. A positive % indicates that the vibration level is above the reference. The results in Figure 3 show that changes in the body structure resulting in reduced stiffness have also reduced the vibration level. This was intuitive, since the torsional mode resonance of the 1st Concept body was too close but below the idle firing frequency. However, the full simulation was able to predict the effect in terms of the vibration amplitude. This points out the problem of setting and tracking sub-system component resonance goals, since exceeding the goal does not immediately illustrate the potential problem. The adage that "stiffer is better" does not always lead to optimum vibration performance as shown in this example (Ref. 3).

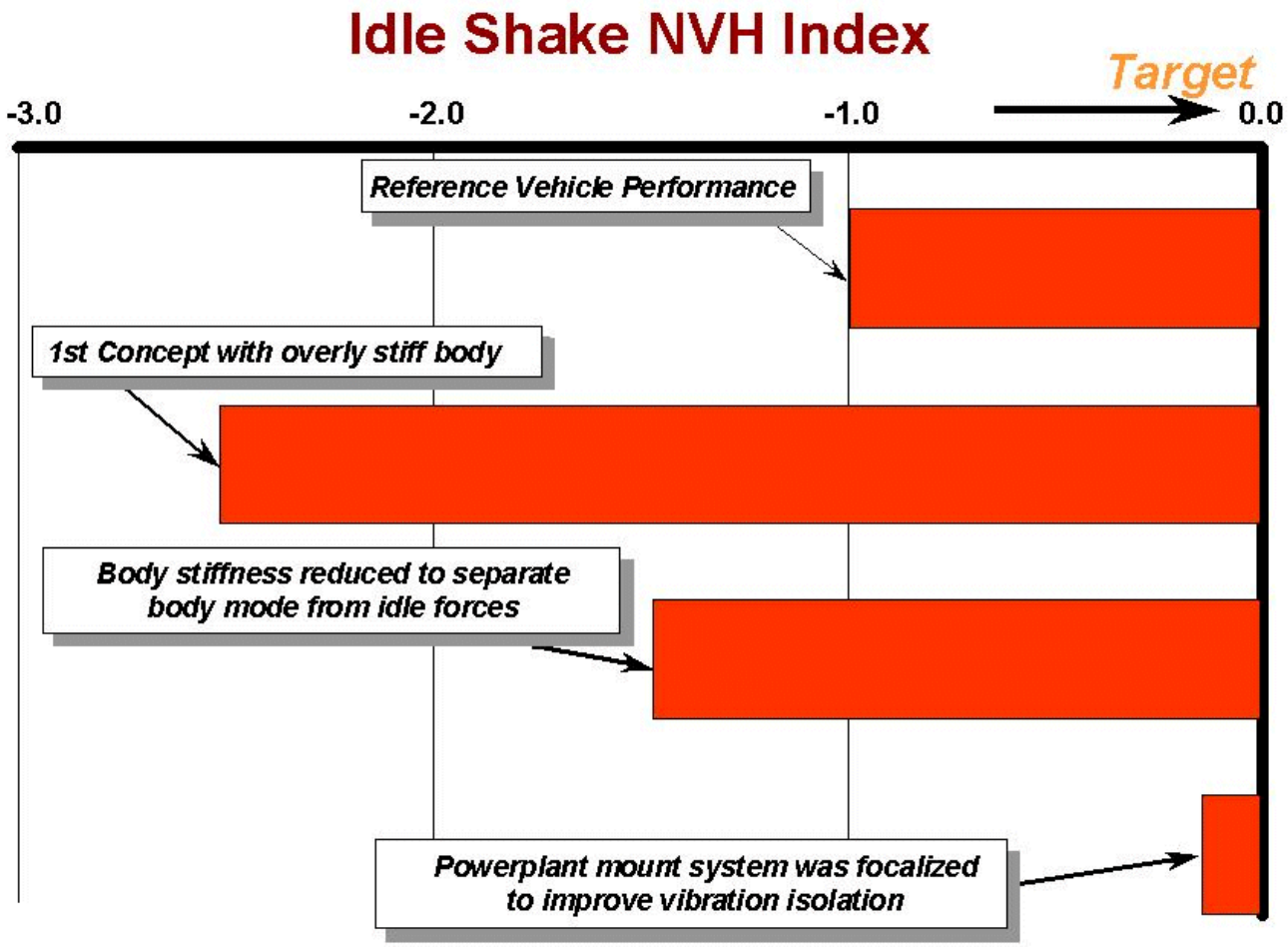

Figure 3: Example Design Evolution from 1st Concept to Near Target Performance

The engine mounting system was focalized (Ref. 5) to lower the rigid body roll mode frequency of the powertrain. Results, using the MSC/NVH_Manager, showed that the additional isolation effect brought the idle performance very near the reference level, as shown by the bottom bar of Figure 3.

This example demonstrates how a vehicle model with sub-system interaction is required to fully understand the two strategies that were utilized to improve NVH performance. The first strategy used modal separation to keep the responding resonance removed from the exciting force. The second strategy used isolation to keep the forces of the engine from being transmitted to the body. A complete vehicle model is needed to quantify these interactive effects.

Powertrain Noise Reduction Example

The simulation of powertrain noise over the complete operating range of the engine includes frequencies from 50 to 500 Hz and higher. In this range the flexibility of the powerplant assembly must be accounted for. The first order bending mode can be from 60 to 100 Hz for a rear wheel drive vehicle. Additionally, the flexibility of some of the suspension links may result in important resonances. Figure 4 shows a display of the chassis sub-systems after detailed models have been added using the "Import" feature of the MSC/NVH_Manager. The Import process used to add the powertrain and suspension link models to the assembly are the same as those used to add the body model earlier. The MSC/NVH_Manager process provides for the detail to be added only when, and if, it is necessary. Since a noise study is to be performed, an acoustic cavity model must also be added and is shown in Figure 5. MSC/NASTRAN's structural-acoustic coupling process was used for the interior noise simulation. The MSC/NVH_Manager provides for an acoustic cavity sub-system to be added to the assembly, and since the coupling procedure is already included in MSC/NASTRAN no additional modeling features are needed.

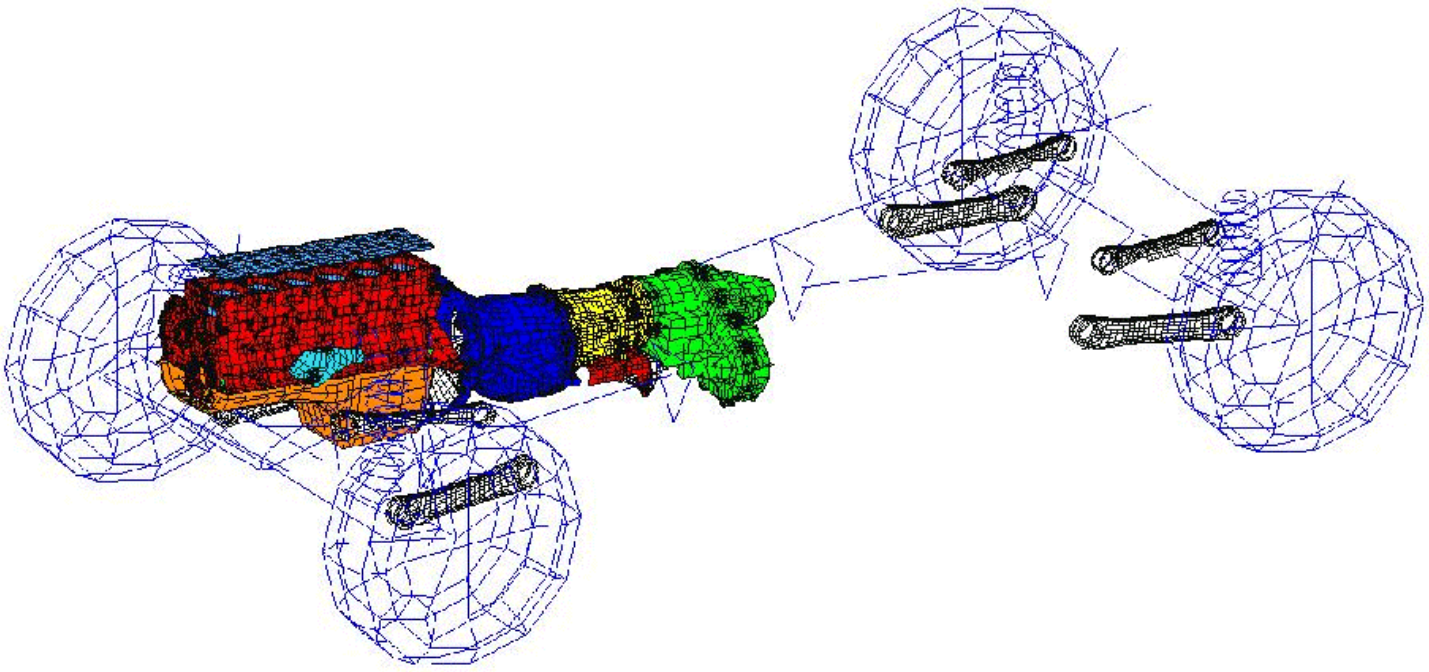

Figure 4: Chassis Sub-Systems including detailed model of powertrain assembly.

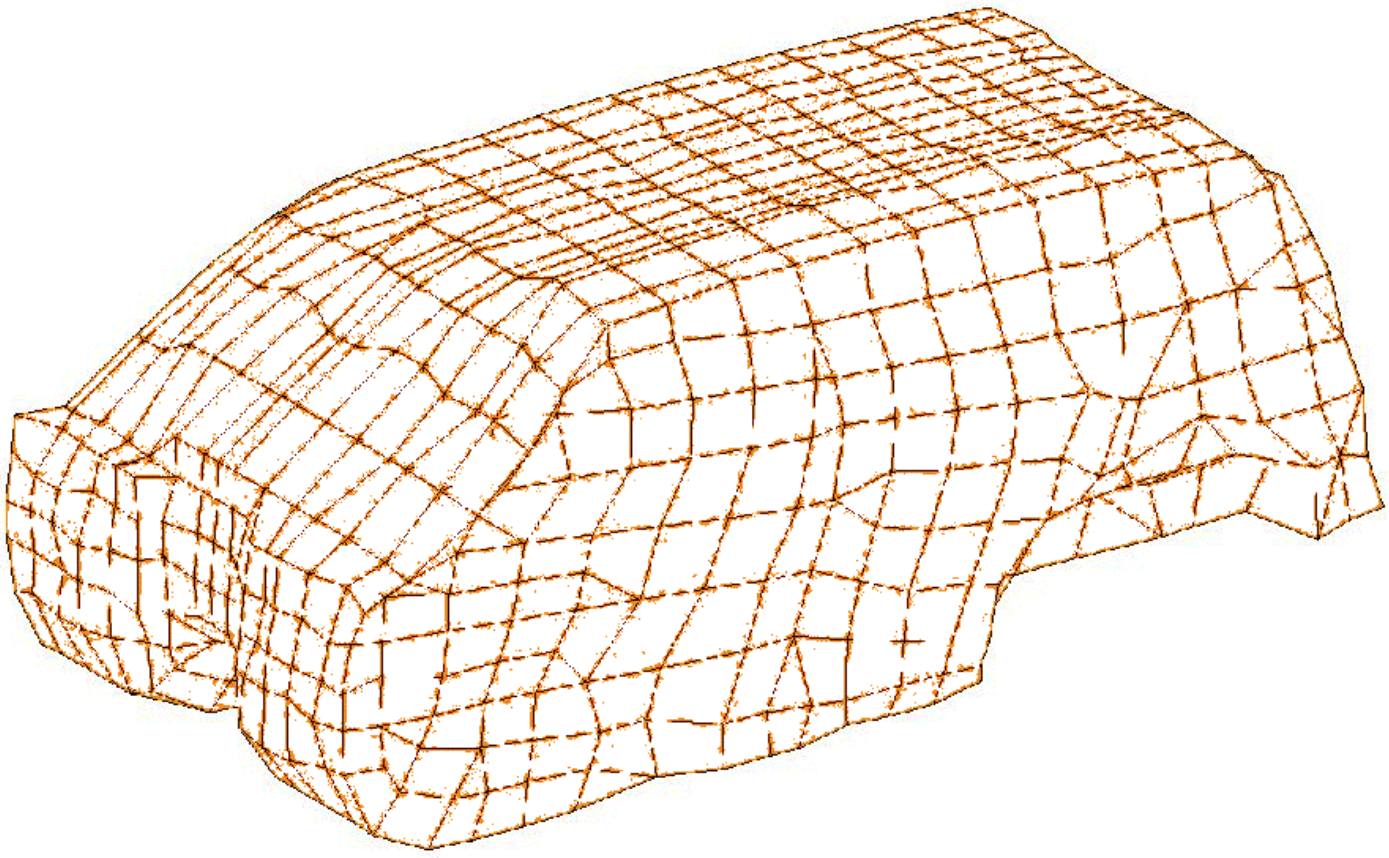

Figure 5: Acoustic cavity model of the passenger compartment air space.

The complete vehicle assembly for powertrain noise simulation is shown in Figure 6. The detailed models of engine, body structure, and suspension are shown. With this detail level, there is sufficient model fidelity to study noise predictions in the range of interest from 60 to 140 Hz. This range corresponded to the frequency of an inherent second order pitch moment of this powertrain for normal operation from 50 to 110 Miles per hour.

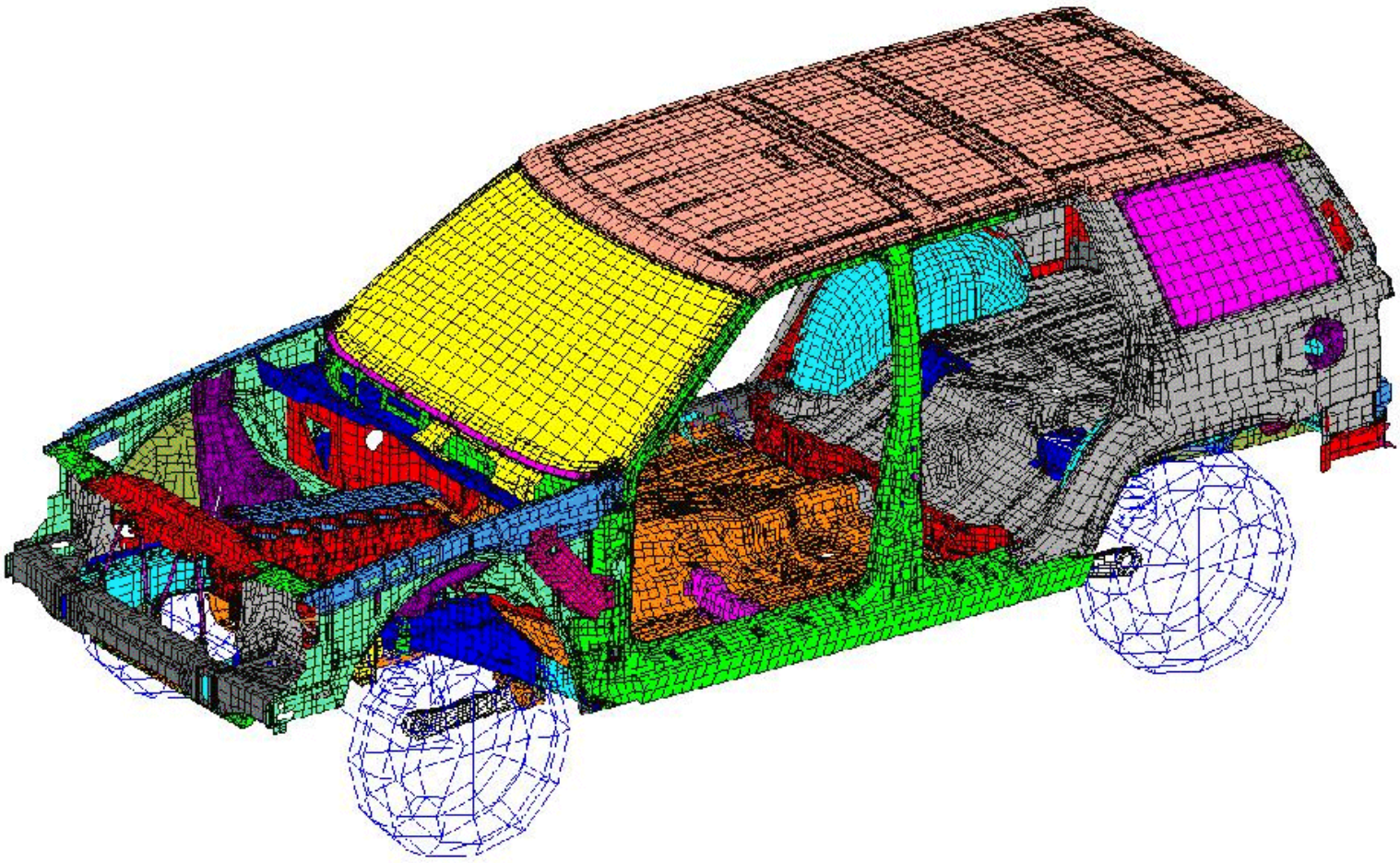

Figure 6: Vehicle assembly with detailed body, powertrain, and suspension.

This particular powertrain was a low volume alternative which had demonstrated undesirable periods of noise when it passed through the powertrain resonances. It was decided that the best design alternatives would be a combination of bending braces and tuned dynamic absorbers. Early studies showed that braces could shift the modes higher but did not attenuate the noise significantly. Root cause finding using operating deformed shape animation from the MSC/NVH_Manager, revealed that the best place for a tuned absorber was at the extreme rear end of the powerplant assembly on the transfer case. The MSC/NVH_Manager has a Tuned Absorber button that can be seen in Figure 1. When the Tuned Absorber is selected, the user is prompted for the mass of the absorber and the

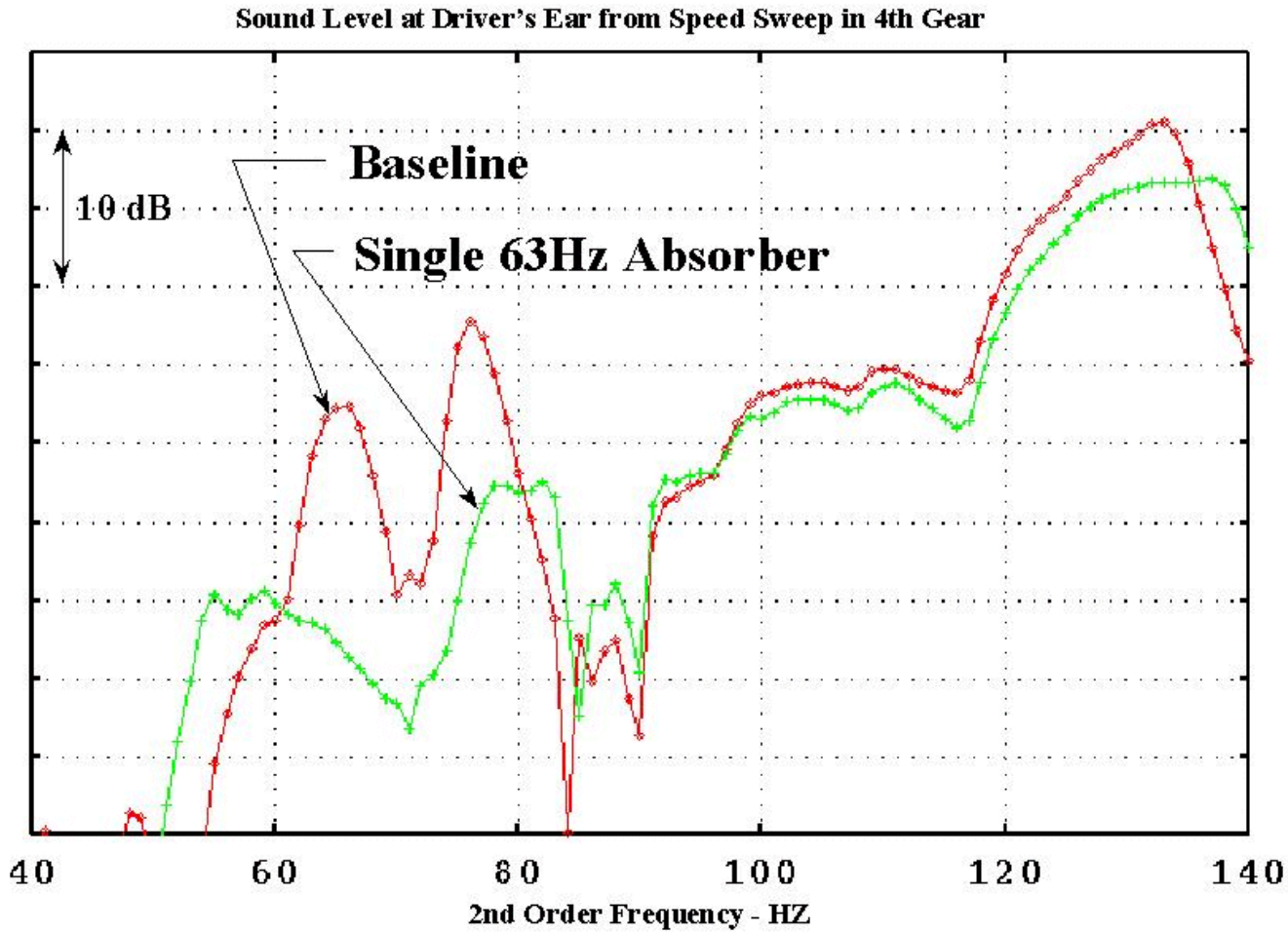

Figure 7: Sound Reduction due to Single Dynamic Absorber tuned to 63 Hz

desired tuning frequency. The MSC/NVH_Manager automatically computes the required spring for a single degree of freedom oscillator at the specified frequency.

Results of the Tuned Absorber studies are shown in Figure 7, where a single 8 lb absorber tuned to 63 Hz has significantly reduced two noise peaks in the 60 to 80 Hz range which was around the first powertrain bending resonances. Noise in the 120 to 140 Hz range would only occur at speeds around 100 MPH. It was felt that the levels would be too high for European applications where this is a normal operating speed. A second absorber at the same location but tuned to 110 Hz was added. The combined effect of two absorbers reduced noise by about 11. dbA in the 120 to 140 Hz region, as shown in Figure 8.

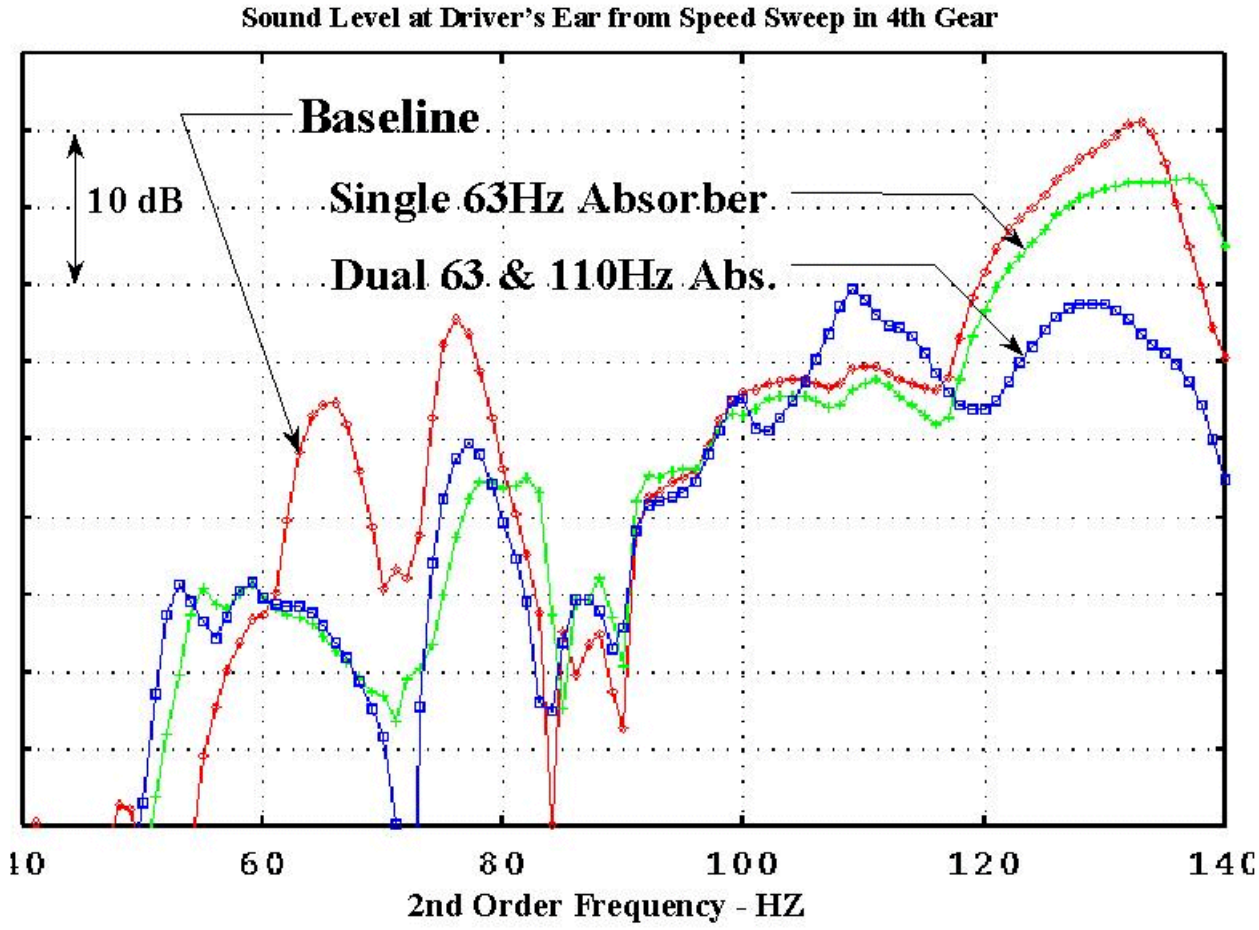

Figure 8: Sound Reduction due to Dual Absorbers tuned to 63 and 110 Hz

Summary

The MSC/NVH_Manager process of formulating full vehicle systems for NVH performance evaluation at Chrysler Corporation has been explained and examples

illustrated. The simulation models provide for real world load conditions to be applied and evaluated for their effect on noise and vibration amplitudes that can be quantifiably related to customer perception of NVH quality. Full vehicle simulations are required to evaluate the interaction between suspension, powertrain, and body sub-systems. Sub-system interactions provide a basis for trade offs and compromises that still meet NVH performance targets within cost, weight, and manufacturing constraints.

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