NVH numerical analysis and concept phase assessment in the car development phase

Marco Danti
NVH & Aerodynamics
Agenda

• Acoustic simulation

• Concept analysis and assessment

• Morphing approach

• Suspension multiattribute optimization

• Body thickness optimization

• Concluding Remarks
Acoustic simulation

Structural Dynamics and structure – borne noise

Structure-borne Paths

• The “Sound Source” is a source of vibrations

• Possible attenuation by suspension elements or mounts (if present)

• Vibrations propagate through the car structure to the walls of the passenger area

• Surfaces radiate sound into the passenger compartment

• Effect of low frequency acoustic modal behaviour

STRUCTURE-BORNE NOISE SIMULATION

Low Frequency Range

Finite Element Approach

Modal Analysis
**Acoustic simulation**

**Air – borne noise**

**Air-borne Paths**

- The “Sound Source” is a source of noise
- Noise propagates through the air, holes and across the surfaces of the structure
- Surfaces give a noise reduction effect (Transmission Loss)
- The noise inside the cabin can be attenuated by the acoustic treatments
- Dominant in high frequency (>500 Hz)

**Acoustic Transfer Function**

\[
\frac{p}{p}
\]

**High Frequency Range**

- FEM / IEM / BEM / SEA Approach
- Modal / Direct / Statistical Analysis

**AIR-BORNE NOISE SIMULATION**
Acoustic simulation

Fluid – structure interaction

Pressure

Acceleration

Force

Fluid structure interaction

A/F

P/F

Experimental

Numerical

Frequency [Hz]

Experimental

Numerical

Frequency [Hz]

This document contains information which are proprietary of CRF. Neither this document nor the information contained herein shall be used, duplicated nor communicated by any means to any third party, in whole or in part, except with the prior written consent of CRF.
Acoustic simulation

CRF software for dynamic simulation

Structure FE Model

NASTRAN Modal Analysis (Sol 103)

Modal Base:
Eigenvectors \( \phi_i \)
Eigenvalues \( \omega_i \)

Modal damping \( b(f) \)

**FRF_UNI©**: Dynamic FRF simulation

\[ \text{Displacement} \rightarrow u_{jk} = \sum_{i=1}^{n} \frac{\phi_{ij} \phi_{ik}}{\omega^2 - \omega_i^2 - ib_i \omega} \]

\[ \text{Velocity} \rightarrow \dot{u}_{jk} = i \omega u_{jk} \]

\[ \text{Acceleration} \rightarrow \ddot{u}_{jk} = -\omega^2 u_{jk} \]

• unit load applied: \( \rho_i(w) = 1 \)

where:

- \( i \) = mode number
- \( j \) = response node and direction
- \( k \) = load node and direction
- \( b \) = modal damping
Acoustic simulation

CRF software for acoustic simulation

FSI_UNI©: Acoustic FRF simulation

Structure FE Model
- Modal Base: Eigenvectors $\phi_{si}$
- Eigenvalues $\omega_{si}$
- Structure Modal damping $b_s(f)$

Cavity FE Model
- Modal Base: Eigenvectors $\phi_{ci}$
- Eigenvalues $\omega_{ci}$
- Cavity Modal damping $b_c(f)$

FSI_UNI©

FRF

Structure Modal Base:
- Eigenvectors $\phi_{si}$
- Eigenvalues $\omega_{si}$
- Structure Modal damping $b_s(f)$

Cavity Modal Base:
- Eigenvectors $\phi_{ci}$
- Eigenvalues $\omega_{ci}$
- Cavity Modal damping $b_c(f)$

Fluid/structure coupling matrix

Fluid structure interaction

Acceleration
Pressure

Force

Coupled analysis

$\begin{bmatrix}
-M\omega^2 + K & -A^T \\
-\omega^2 A & -M_f\omega^2 + K_f
\end{bmatrix} \begin{bmatrix} u \\ p \end{bmatrix} = \begin{bmatrix} F \\ 0 \end{bmatrix}$

where

- $[M] = \text{Structural mass matrix}$
- $[K] = \text{Structural stiffness matrix}$
- $[A] = \text{Matrix of surface contact area}$
- $[M_f] = \text{Acoustic “mass” matrix}$
- $[K_f] = \text{Acoustic “stiffness” matrix}$
- $\{u\} = \text{Vector of structural displacements}$
- $\{p\} = \text{Vector of acoustic pressures}$
- $\{F\} = \text{Vector of applied forces}$
Acoustic simulation
CRF software for acoustic simulation

**FSI_MP®, PFE®:**
Acoustic FRF analysis (Panel, Modal and Load Participation)

Panel Participation Evaluation

Critical acoustic FRF Response

Modal Participation Evaluation
Acoustic simulation

Tools for improvement – free damping layer opt.

Standard FE analysis

- Time consuming
- Mesh intensive
- No way to account for frequency variation

New and approximated FE analysis

- Main characteristic are retained in the simplified model (M K and η)
- Quick procedure to assess several combination of different FLT thicknesses
Acoustic simulation

Tools for improvement – free damping layer opt.

Numerical Simulation

Bare structure modal analysis

Damping treatment patches analysis

Patch n

\[
\begin{bmatrix}
K \\
M
\end{bmatrix}
\]

Damping treatment optimisation

Data exchange with experiment

Bare structure modal matrices

\[
\begin{bmatrix}
\phi \\
\omega
\end{bmatrix}
\]

Structural damping matrix

Structure with damping treatments

Multi-objective Optimisation by Genetic Algorithms

Baseline treatments

Optimised treatments

Results of the optimized configuration - red patches are the most effective ones

Worst

BEST

APIC

WEIGHT

Pareto Frontier

Baseline treatments

Optimised treatments

Structure with damping treatments

6-7 / 06 / 2011

NVH numerical analysis and concept phase assessment in the car development phase

This document contains information which are proprietary of CRF. Neither this document nor the information contained herein shall be used, duplicated nor communicated by any means to any third party, in whole or in part, except with the prior written consent of CRF
Concept analysis and assessment

- Scenario Analysis and product concept definition
- Strategic Set up
- Technical set up
- Technical and technological development
- Tooling and ramp - up

Concept assessment

- Vehicles derived by the same platform
  - Global morphing approach – greenhouse modifications
- Development and application of brand new ideas
  - Concurrent multidisciplinary approach
- Optimization of the reference concept model
  - Evaluation of different material and thickness
**Concept analysis and assessment**

**Morphing approach**

---

**Chassis development**

- **Constraints and carryover parts**
- **Further requirements**
- **Further requirements**

**Marketing specifications**

**Body development, closures and management of the different shapes of body**

**Concept phase**

Shape definition starting from preexisting chassis
- first step – global dimensions
- second steps – local refinement (can be handled upto the final design release with increase in cost)

---

**VECOM**

Vehicle Concept Modelling
Concept analysis and assessment

Morphing approach

Morphing techniques have been exploited as a means for the estimation of the global shape variables definition and their impact on the performances.

The performances considered so far are:

- Static strength (torsion and bending)
- Elastic line deformation
- Frequency (bending and torsion)
- Dynamic stiffness of the suspension, engine attachments points
- P/F transfer functions from the abovementioned points towards the drivers’ ear
- Ergonomics angle and length
Concept analysis and assessment

Morphing approach

Global variables

Optimization goals

(indexes created to summarize the average value with respect to a predefined threshold)
Concept analysis and assessment

Suspension multiattribute optimization

Ride and Handling (RH) performance

Noise Vibration & Harshness (NVH) performance
Concept analysis and assessment
Suspension multiattribute optimization

Trimmed body FEM model

MSC/Nastran Simulation

FEM Suspension model

Experimental hub accelerations on road test

Noise (dB)

Numerical Experimental

Frequency (30-250 Hz)
Concept analysis and assessment
Suspension multiattribute optimization

**Optimisation parameters:**

**Variables**
Front suspension bushings stiffness

**Objectives**
Rolling noise reduction

**Constraints**
Min and max stiffness for each bushing

**Optimisation method**
Multi-objective Genetic Algorithms

---

**Baseline vs Optimised**

- **Delta = 3.1 dB(A)**
- **Delta = 3.3 dB(A)**

---

**1/3 Octave Band Spectra**

- **Delta = 10 dB**

---

6-7 / 06 / 2011

NVH numerical analysis and concept phase assessment in the car development phase
Concept analysis and assessment
Suspension multiattribute optimization
Concept analysis and assessment

Body thickness optimization

Concept optimization of specific parts of vehicle in the concept phase

Target: increase dynamic stiffness
Variables: thickness of specific sheets (33)
Constraint: mass of the concept (1 of 2)

Variable thicknesses in the overall range [0.7 3.0] mm

Constraints of the optimization
Concept analysis and assessment

Body thickness optimization

**Target:** increase dynamic stiffness

**Variables:** thickness of specific sheets (33)

**Constraint:** Nobody
Concept analysis and assessment

Body thickness optimization

**Target:** increase dynamic stiffness

**Variables:** thickness of specific sheets (33)

**Constraint:** Mass less than 101%

<table>
<thead>
<tr>
<th>Weight (%)</th>
<th>Minimum dynamic stiffness (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Starting</td>
<td>Optimal</td>
</tr>
<tr>
<td>Starting</td>
<td>Optimal</td>
</tr>
<tr>
<td>Ottimizzazione 7</td>
<td>100.00</td>
</tr>
</tbody>
</table>
Concept analysis and assessment

Body thickness optimization

Results of optimization

Point inertance

Base

Ottimizzazione 1

Ottimizzazione 2
Concluding remarks

- In challenging markets it is important to decrease the time to market in order to meet the customers’ needs

- The exploitation of virtual analysis is crucial in both the development phase and the concept phase of the new products

- All the performances, that can be simulated in the early phase of the design, can concurr to the choices of the best tradeoff of different - usually conflicting – targets

- The results of these analysis, even if not fully reliable, can drive and address the subsequent development phase
Thank you for your attention