OVERVIEW OF CAE IN AUTOMOTIVE NVH
STATUS AND FUTURE EVOLUTION
01 - Introduction

MAIN STAKES OF CAE

Reduce development cost
- Anticipate counter-measure

Decrease Development Time
- « Zero physical prototype process »

Improve NVH performance
- Ensure customer satisfaction & follow market trend

Find Breaking Design
- Optimized design for multi-performance
01 - Introduction

CAE « REVOLUTION »

FEM - NVH Vehicle Model Size & Run Time

- Run Time
- Model Size

MODEL SIZE M-DOF

RUN TIME (h)


0 10 20
Subjective

Objective

Customer Satisfaction Target - Survey

Performance Target Level – Full Vehicle

Performance Target Level – System Level

Performance Target Level – Part Level

1st order simple cascading tools

Full CAE

Synthesis 0D-1D

System Optimum

• CAE

• 0D-1D Simulation

• CAE

Design Performance Sound Evaluation

Design Performance Evaluation – Full Vehicle

Design Performance Evaluation – System Level

Design Performance Evaluation – Part Level

02 – CAE Performance evaluation

Driver sound simulator & Real Time TPA

DEA-TDS
PH MORDILLAT
APRIL 27TH 2017
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ROAD NOISE CASCADING EXAMPLE

\[ P = \frac{S}{F} + \frac{F}{F} \times P/F + Ptire \times P/P \]

- **Vehicle Targets**
- **Subsystem Targets**

- **Complex CAE models**
- **Less complex CAE models**

**A/F, Global modes**
- Structure borne
- Air borne

**TL, Alpha**
- Tire/road
- Acoustic package
1. Full vehicle Pro’s

- Simulates directly customer level performance
- subsystem “strong” coupling effects are considered
- can be used for target deployment
- useful in problem solving

2. Full vehicle Con’s

- Complex and time consuming (modeling and run time)
- Complex Data management for model building
- Data cross evaluation to ensure result robustness

- From Test Transfer Path Analysis: “Weak” or “Strong” coupling
02 – CAE Performance evaluation

- Mixed Approach – Synthesis Model
  - Difficulty to define “worst combination”
  - Easy Model combination for full performance evaluation

Normal Roof  Fixed Sun-Roof

3 Diesel PWT
4 cylinders – 2 different Power
1 AT + 2MT

3 Gasoline PWT
3 cylinders + 4 cylinders - 2 different Power
1 AT + 2MT

24 combination for Booming Noise without trim level diversity

CAE Analysis Time

Full CAE  Synthesis
02 – CAE Technical Issues

Mechanical Excitation

Air-born Noise & Radiated Noise

Solid & Air-born Interior Noise / Vibration

Aero-Acoustic

Contact / Friction Noises
Brake Squeal – Squeak & Rattle

CAE NVH
## 02 – CAE Methodologies

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03 – CAE Methodologies

RADIATED NOISE – EXTERIOR ACOUSTIC

1. **FEM (FINITE ELEMENT METHOD)** – “LOW FREQ”
   - **Pro’s**: Matrix conditioning & symmetric
   - **Con’s**:
     - Volume meshing
     - Open field Radiation not native to the method
   - Solving Algorithm: Direct
   - Sommerfeld Conditions (Open Field)
     - BEM / SEA Coupling
     - Finite Elements
     - PML (Perfectly Matched Layer)

2. **BEM- FMM (FAST MULTipoLE METHOD)** – “MID FREQ”
   - Based on BEM Method
   - Faster Matrix assembling Method than BEM
   - Efficient in case of « High » Frequencies
   - Direct and Non-direct solving Methods
03 – CAE Methodologies

EXTERIOR ACOUSTIC – PASS-BY NOISE ATF

Low Frequency Range
Medium Frequency Range
High Frequency Range

100Hz  630Hz  2000Hz  5000Hz

ATF Engine -> Microphone 2

ATF Tire -> Microphone 1

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03 – CAE Methodologies

FRICTION NOISE

1. **FEM** (NON-LINEAR PRE-LOADING & INSTABILITY STUDY)

   - **Mesh** (specifications requirements)
   - **ABAQUS**
   - **STEP 1** (Pre-loading parameters)
   - **STEP 2** (Pressure applying)
   - **STEP 3** (Disc rotation)
   - **STEP 4** (Real model analysis)
   - **STEP 5** (Complex model analysis - outputs: SP, ST, SE)

   ![Diagram of FEM process]

   Real CAE for Disc/PAD contact pressure System Level CAE
   210 combination evaluated -> Break Squeal Risk
CONTACT NOISE

1. **E-LINE METHOD FOR BSR (BUZZ SQUEAK AND RATTLE)**

![E-line set up in SnRD](image1)
![Virtual shaker bench](image2)
![Post-processing in SnRD](image3)
03 – CAE Methodologies

CONTACT NOISE

1. **E-LINE METHOD FOR BSR (BUZZ SQUEAK AND RATTLE)**

   ![CAE Results (SnRD)]
   - Relative displacement (magnitude)
   - Rattle: Dynamic tolerance
   - Squeak: max peak to peak

   ![Test Results]
For styling choice impact for NVH Aero-acoustic performance

1. Predict flow induced “acoustic” excitation thanks to CFD analysis (LBM or RANS method) to reproduce wind-tunnel condition.

2. Excitation is projected to structure mesh and frequency domain

3. New Frequency domain excitation result as an input excitation for the structure NVH cabin noise analysis. Both result on:
   - Glazing vibration
   - Ear noise

Can be obtained from this coupled analysis.
03 – CAE Methodologies

« MECHANICAL » EXCITATION

- GEAR WHINE NOISE

Gearbox model with three gear pairs and flexible casing

FFT – Noise Prediction for Moving Mechanisms
03 – CAE Methodologies

STRUCTURE BORNE

- **FEM (FINITE ELEMENT METHOD)**

Both Structure and Cavity need to have accurate behavior in order to make accurate NTF forecast

- Structure behavior role is dominant in idle condition
- Cavity accuracy is dominant for mid-high RPM range booming

Detailed 2D-3D parts meshing

Material and Connection property
STRUCTURE BORNE

- STRUCTURE MODEL

Accurate modelling rules
- Rigorous data management and building process

⇒ Accurate Vibration response models
03 – CAE Methodologies

STRUCTURE BORNE

- CAVITY MODEL

- Standard Cavity modelling is not accurate enough
- Behavior can be corrected thanks to damping or fluid equivalent modelling for foam parts

→ Behavior is improved but not perfectly correlated
03 – CAE Methodologies

STRUCTURE BORNE

• TRIM PARTS PEM MODELLING

Full PEM model

New PEM modelling equation system

\[
\begin{bmatrix}
Z_{ss} & C_{sc} \\
C_{sc}^T & A_{cc}
\end{bmatrix}
\begin{bmatrix}
\gamma \\
\pi
\end{bmatrix}
=
\begin{bmatrix}
\phi \\
\psi
\end{bmatrix}
\]

Standard Coupled Matrix system

\[
Y = \begin{bmatrix}
Y_{ss} & Y_{sc} \\
Y_{sc}^T & Y_{cc}
\end{bmatrix}
\]

Structural DOF

Fluids DOF

Trim component Impedance Matrices

\[
\begin{bmatrix}
Z_{ss} & C_{sc} \\
C_{sc}^T & A_{cc}
\end{bmatrix}
+ 
\begin{bmatrix}
Y_{ss} & Y_{sc} \\
Y_{sc}^T & Y_{cc}
\end{bmatrix}
\begin{bmatrix}
\gamma \\
\pi
\end{bmatrix}
=
\begin{bmatrix}
\phi \\
\psi
\end{bmatrix}
\]
STRUCTURE BORNE

• TRIM PARTS PEM MODELLING

- PEM Cavity modelling is highly improved
- Behavior is accurately predicted thanks to trim parts FD modelling
- PEM analysis are still time consuming

→ Behavior is improved specially for mid-frequency or complex trim package

Cavity ATF Correlation – Trim Modelling 2

PEM Trim parts models
STRUCTURE BORNE

• NTF CORRELATION RESULTS

Good accuracy can be achieved from CAE NVH for structure borne thanks to:
• Accurate structure models
• Accurate cavity models
03 – CAE Methodologies

OPTIMIZATION

1. SHAPE OPTIMIZATION

Panel Vibration Transfer Function Improvement

Draft result from Shape Optimization

CAD Final Design

2. PARAMETRIC OPTIMIZATION

Variables: bushing stiffnesses, geometry, mass distribution, components materials

- Objective function for NVH
- Objective function for Handling
- Objective function for Comfort

Suspension NVH index [MSC_Nastran]

Weighted sum of K&C linearized characteristics [MSC_Adams]

Parameter related to seat attachment acceleration due to comfort tests [MSC_Adams and MSC_Nastran]

Multi Objective and Multi Discipline Optimization

FCA – MSC/NASTRAN User Conference 2012
03 – CAE Methodologies

PERFORMANCE VARIABILITY

Out of plant Engine noise booming performance variability – 15 vehicles

Variability comes from NTF

It is possible to reproduce this variability thru CAE

Probabilistic parameter change

Normal Law

Uniform Law
08 – Conclusions

• Status of CAE NVH

- CAE is able to cover the whole scope of NVH
- Computer efficiency make CAE forecast possible
- Model complexity becomes higher
- Data & model building process management are the key for CAE success

• Trends

- Mid Frequency methods challenged by LF and HF methods
- Generalized Optimization
- Process impact to NVH behavior
- Co-simulation for high complexity model
- Generalized time domain with high speed analysis

Case 1) Constant thickness with no stamping effects (Conventional method).
Case 2) Variable thickness due to stamping process with inverse method
Case 3) Variable thickness due to stamping process with incremental method.
THANK YOU