
BETA
SIMULATION SOLUTIONS
Ground breaking
Simulation Solutions
physics on screen

Evaluation of Interior Noise Based on Loads from a Multi Body Simulation

An Integrated BETA Suite Solution for Addressing Non-Linear Mounts

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Background

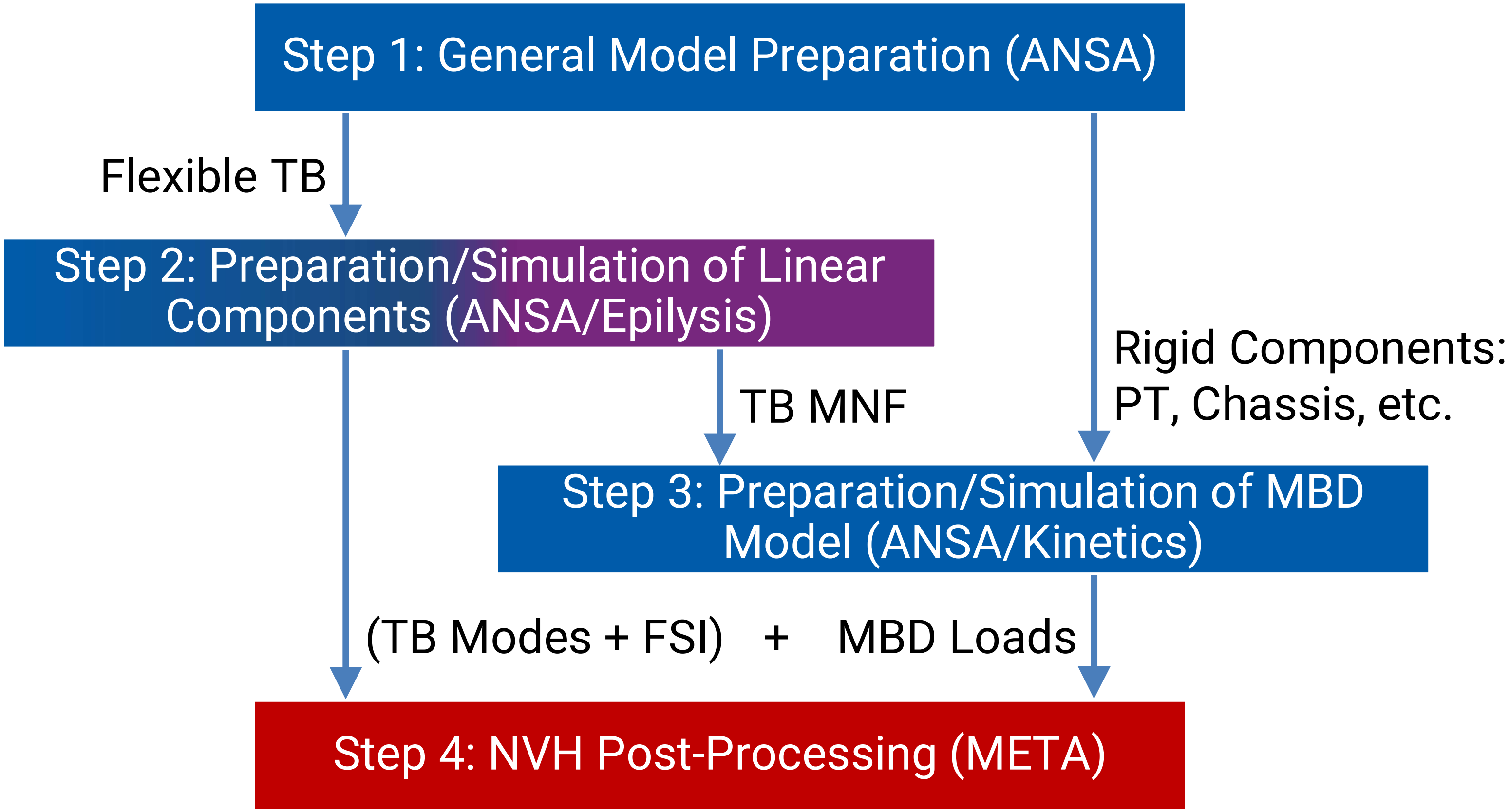
- **Ride comfort** and **NVH performance** are important criteria for any car development process

- Classical NVH analysis uses linear FE models and linear calculation algorithms. However, important structural parts of a vehicle chassis have non-linear properties.

- MultiBody Dynamics (MBD) analysis is a method to calculate the dynamics of complex systems, like a car in driving conditions, including non-linear effects

- We are offering a process inside the BETA suit that combines MBD in ANSA Kinetics with linear NVH calculations on a Trimmed Body

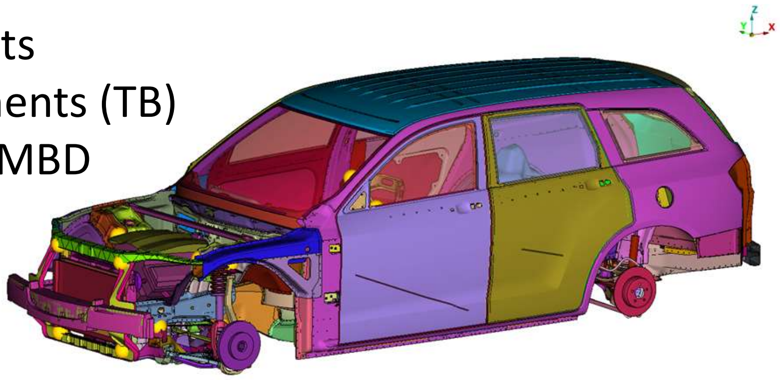
Process


Step 1: General Model Preparation (ANSA)
Flexible TB
Step 2: Preparation/Simulation of Linear Components (ANSA/Epilysis)
TB MNF
Rigid Components: PT, Chassis, etc.
Step 3: Preparation/Simulation of MBD Model (ANSA/Kinetics)
(TB Modes + FSI) + MBD Loads
Step 4: NVH Post-Processing (META)

Detailed Process Description

Step 1: General Model Preparation

Structural Components
- Flexible Components (TB)
- Rigid Bodies for MBD



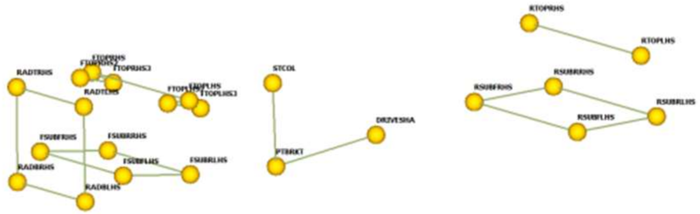
Acoustic Cavity with
ANSA Cavity mesh tool

ANSA
PRE PROCESSOR

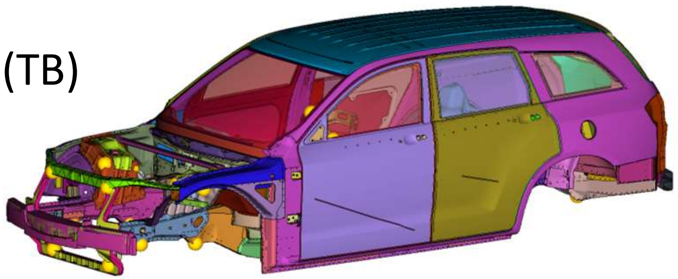
1. Provision of all required components (including acoustic cavity)
2. Preparation of TB for linear solver, e.g.
   – Connections
   – Trim masses
   – Properties/Materials
3. Preparation of Subframes, Powertrain, Engine, Radiator for MBD solver:
   – Masses, Inertias
4. Preparation of cavity mesh

Step 1: General Model Preparation

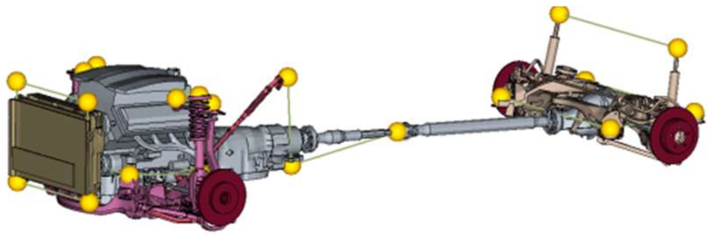
Interface points



Flexible Component (TB)
ANSA data base I

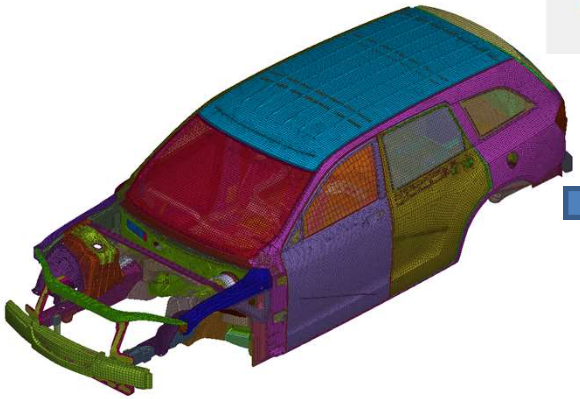


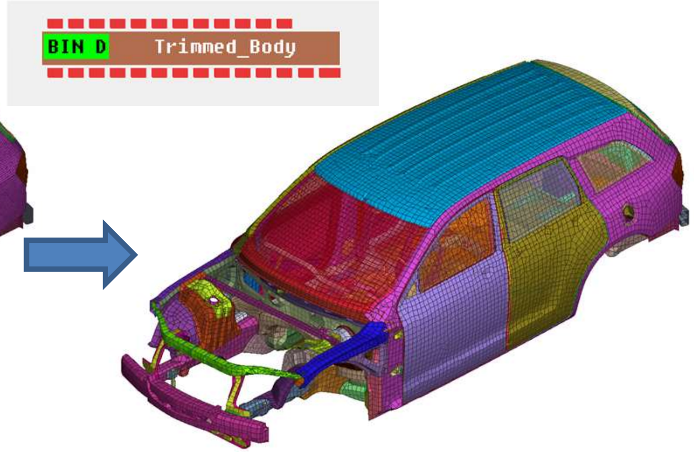
MBD Components
ANSA data base II



- Definition of interface points
  - Common position in linear model and MBD model
  - Field 10 names for NVH-Console and grid ID scheme for force table definition
- Divide ANSA data base into
  - TB for linear calculation
  - Rigid Body components for MBD

Step 2: NVH Model Preparation – Display Model





Features Full FE:

- 900K elements
- 750K grids

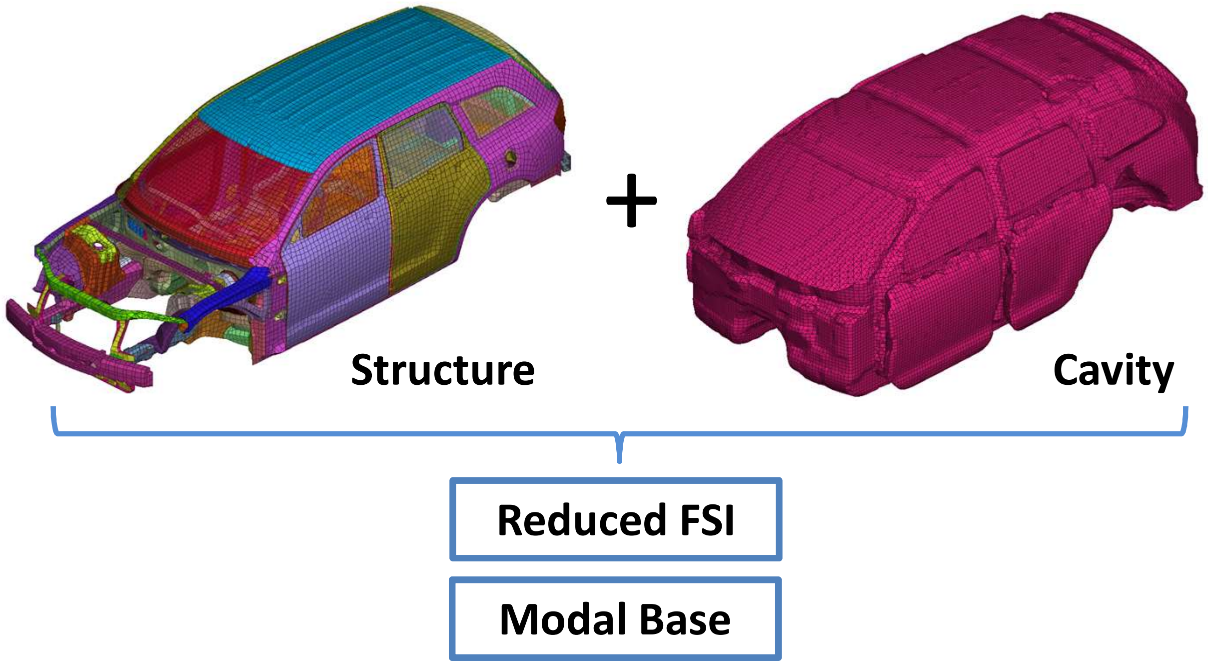
Features Display Model:

- 60K elements
- 60K grids (subset of Full FE grids)

- Preparation of model from data base I in ANSA NVH-Console
- NVH-C model consists of one component (TB with cavity)
- NVH-C Step I: Creation of Display Model in NVH-C as model reduction technique

Display Model in NVH-C is Key Enabler for Manageable File Size of Modal Base

Step 2: Calculation of FSI and Modal Base



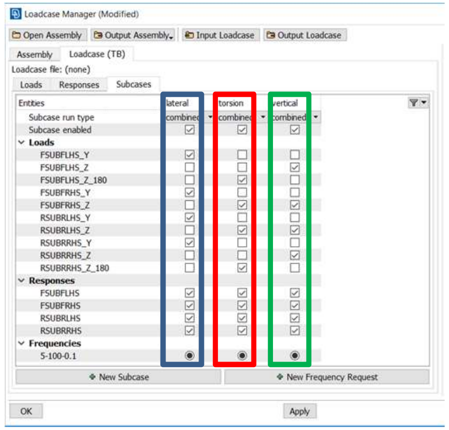
Epilysis/AMLS is Key Enabler for Efficient Calculation of Modal Base

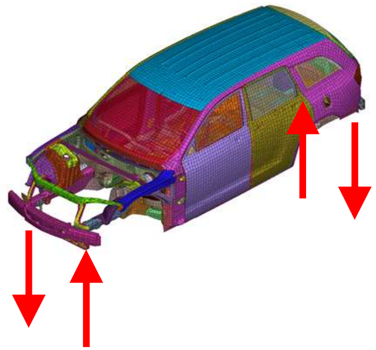
ANSA PRE PROCESSOR

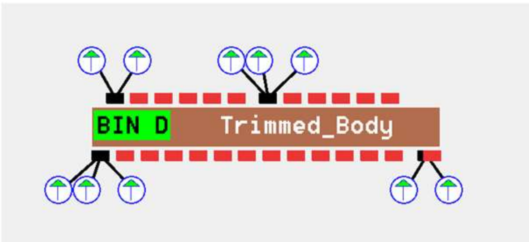
EPILYSIS SOLVER

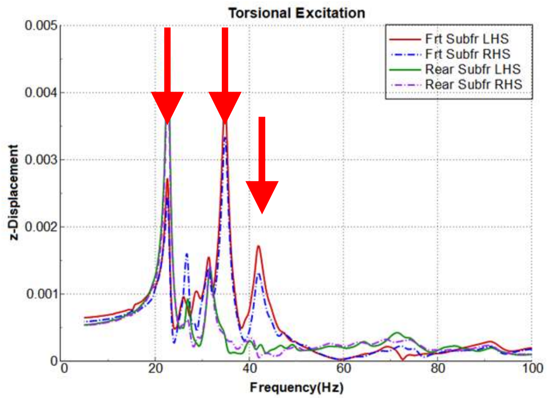
- NVH-C Step II: Creation of reduced rep. of Fluid Structure Interaction (FSI)
- NVH-C Step III: Preparation of SOL103 decks for of calculation of modes:
  - Cut-off 250Hz
  - With Resvec
- NVH-C Step IV: Solving SOL103 decks with Epilysis/AMLS

Step 2: Global Modes Analysis







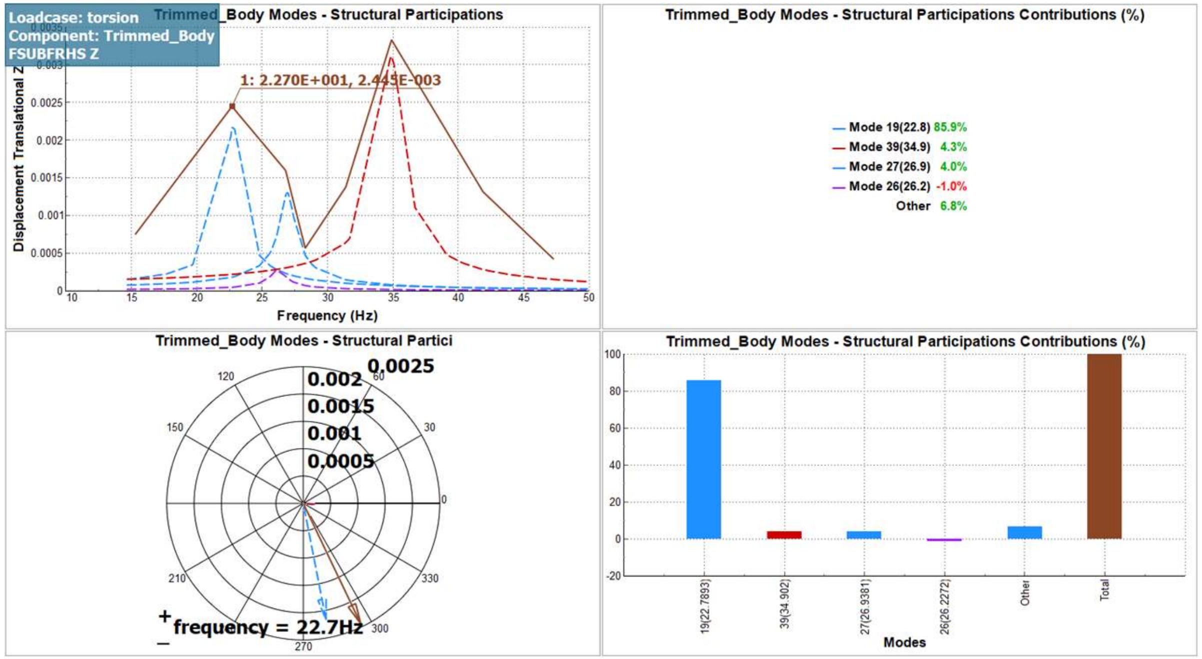


ANSA PRE PROCESSOR

META POST PROCESSOR

- NVH-Console: Easy set up of dynamic load cases to excite global
  - Lateral modes
  - Torsional modes
  - Vertical modes
- Response curves, calculated from modal base, show the resonance frequencies
- Example Torsional mode: 22.8Hz, 34.4Hz, 41.7Hz

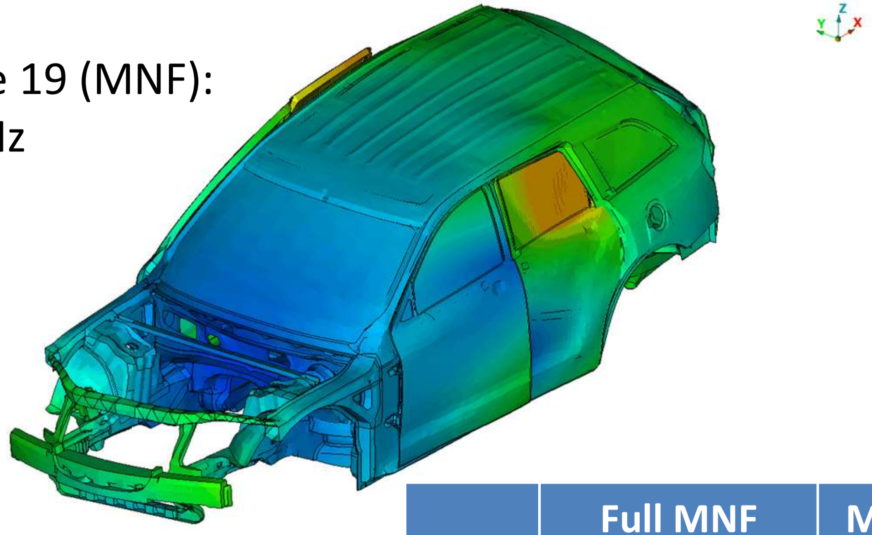
Step 2: Global Modes Analysis



- NVH-C: Easy set-up of modal participation calculation for dynamic responses
- NVH-C controls META via session files
- Example: Modal participation for torsional load case
- **Result:** Main contribution to torsional resonance at 22.8Hz: Mode 19

Step 2: Calculation of MNF File

Mode 19 (MNF): 22.8Hz



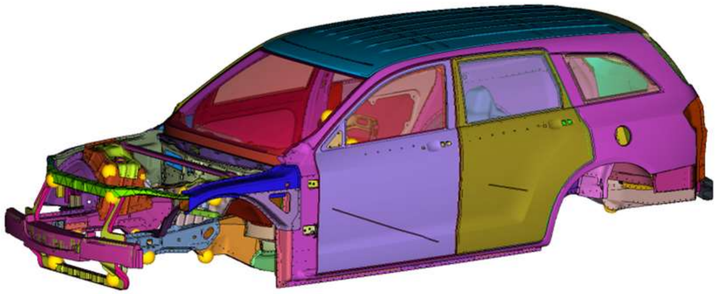
	Full MNF	MNF Display
Size	7.0 GB	600 MB

Using a Display Model is Key Enabler for Manageable File Size of MNF used in MBD Run

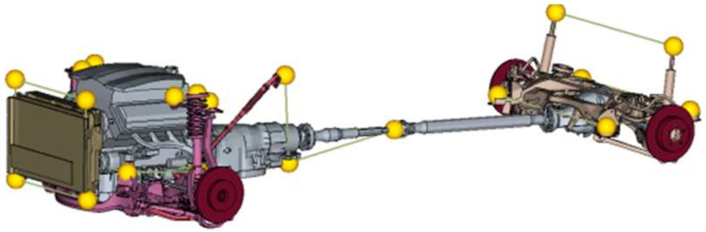
EPILYSIS SOLVER

- Epilysis can calculate MNF file using (NVH) **Display Model** which leads to drastically reduced MNF file size (**new feature!**)
- MNF can be displayed/ checked in META
- **Cut-off frequency** for MNF calculation taken from global mode analysis (50Hz)

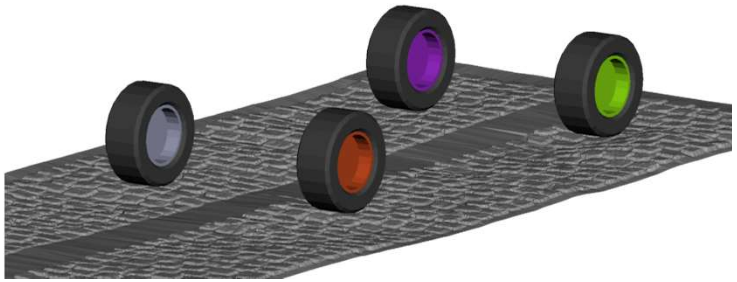
Step 3: Kinetics – Model Preparation



Trimmed Body
(Flex Body/Rigid Body)



Suspension, Powertrain,
Radiator (Rigid Bodies)



Tire-Road Interaction

ANSA
PRE PROCESSOR

Flex Body (Trimmed Body) and **Rigid Bodies** (Suspension, Powertrain, Radiator)

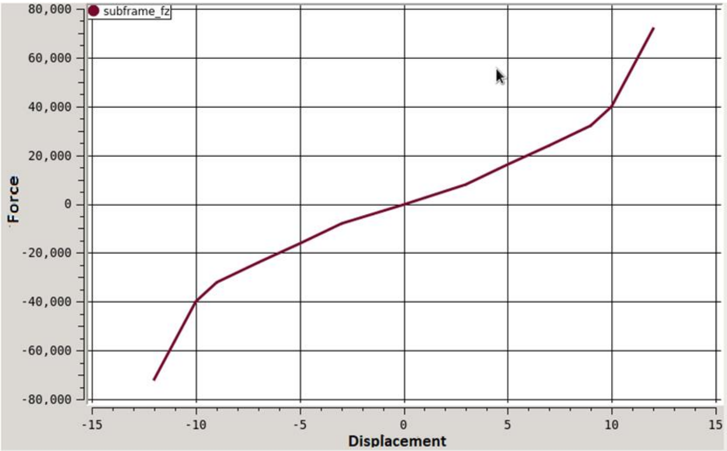
- Require the definition of bodies, joints, bushings

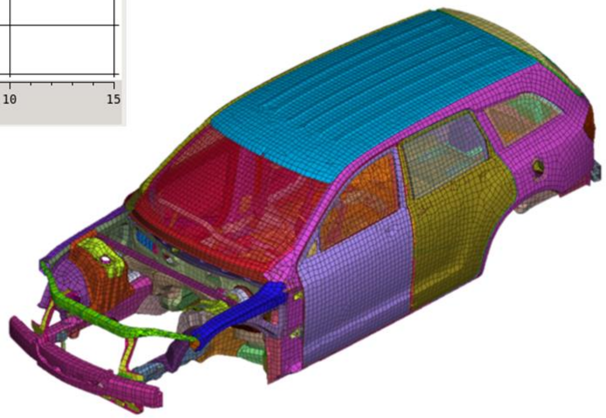
Tire-Road Interaction

- Requires tire and road entity definitions

Step 3: Kinetics – Model Preparation

Frt Subfr, z-dir: F(s) curve

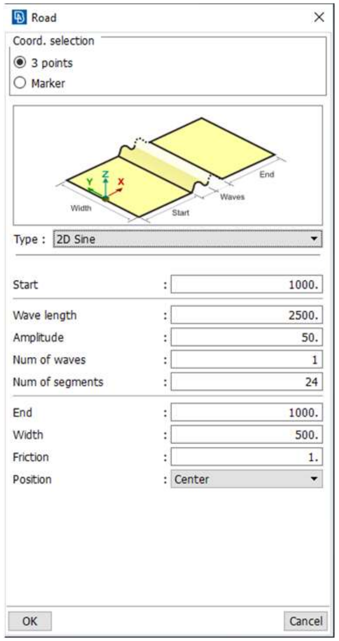




NVH Display Model used for Flex Body in MBD

- Non-Linear stiffness curves of bushings via:
  - Tables
  - User expressions
  - Python scripts
- Trimmed Body variants:
  - Rigid
  - Flex Body/Full MNF
  - Flex Body/Display MNF
- MNF (Full/Display) can be created directly in ANSA Kinetics

Step 3: Kinetics – Tire-Road Interaction



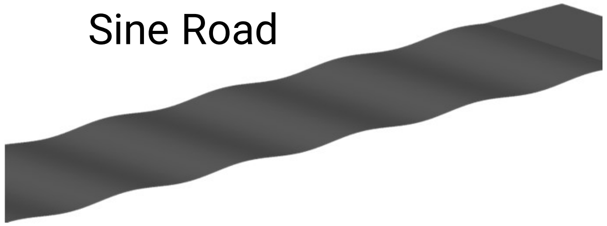
PAC2002

- Tire formulation embedded in ANSA Kinetics
- For road frequencies < 8Hz

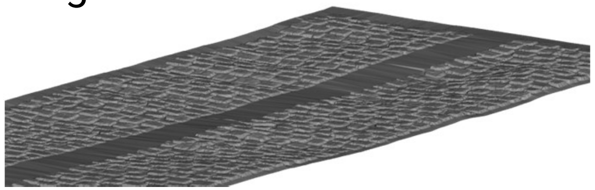
FTire

- Advanced tire formulation including effects of tire belt
- For road frequencies < 250Hz

Sine Road



Belgian Block



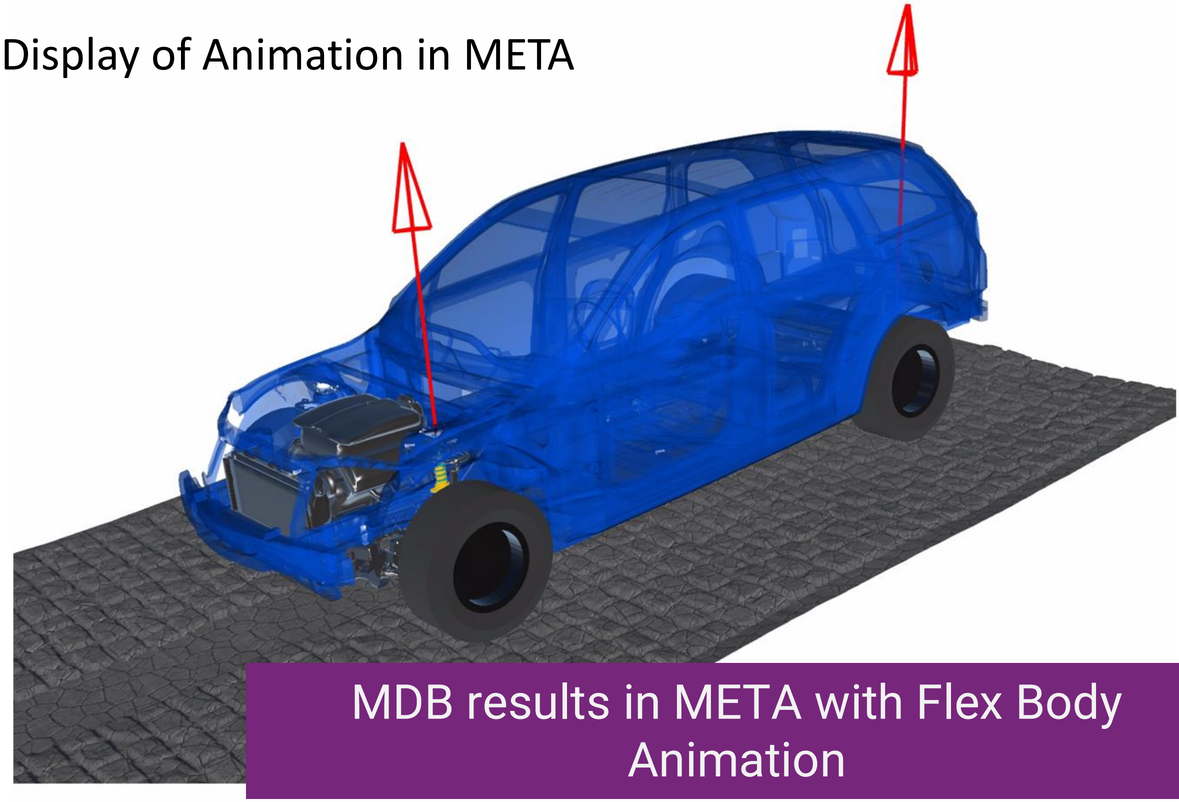
ANSA PRE PROCESSOR

Variants:

- Two different tire formulations:
  - PAC2002 (Pacejka)
  - FTire
- Two different road surfaces modelled:
  - Sine Road (26Hz)
  - Belgian Block Road
- Road Builder supports the parametric construction of different road surfaces

Step 3: Kinetics – Simulation of Driving Car on Road

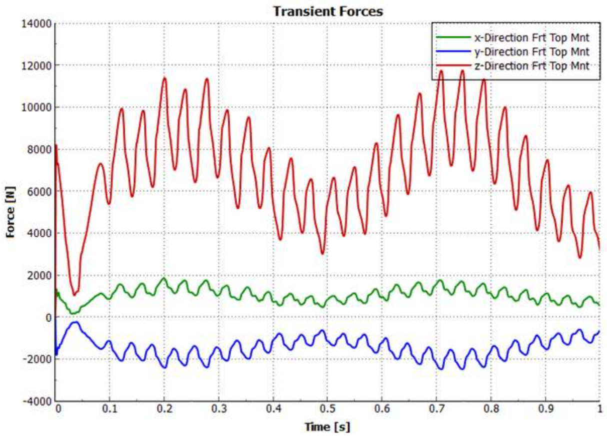
Display of Animation in META



MDB results in META with Flex Body Animation

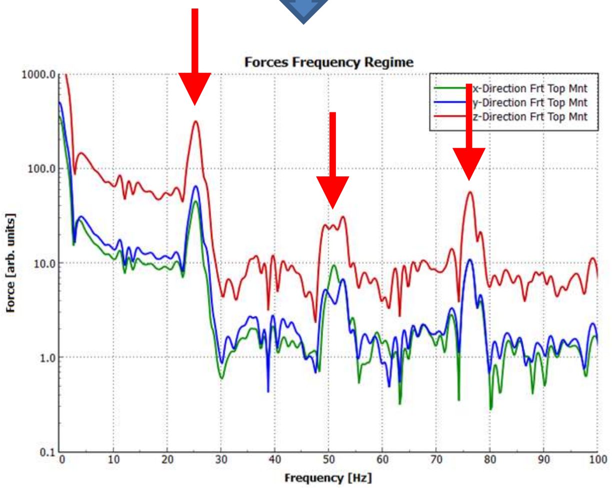
- Several MBD load cases have been simulated in time domain depending on
  - Type of TB: Rigid Body/Flex Body
  - Tire formulation
  - Road surface
- Overall simulation time: T = 1s
- Vehicle speed: v = 54Km/h

Step 3: Kinetics –Preparation of Loads



force(t) $\circ\!\!-\!\!\bullet$ Force(f)

FT



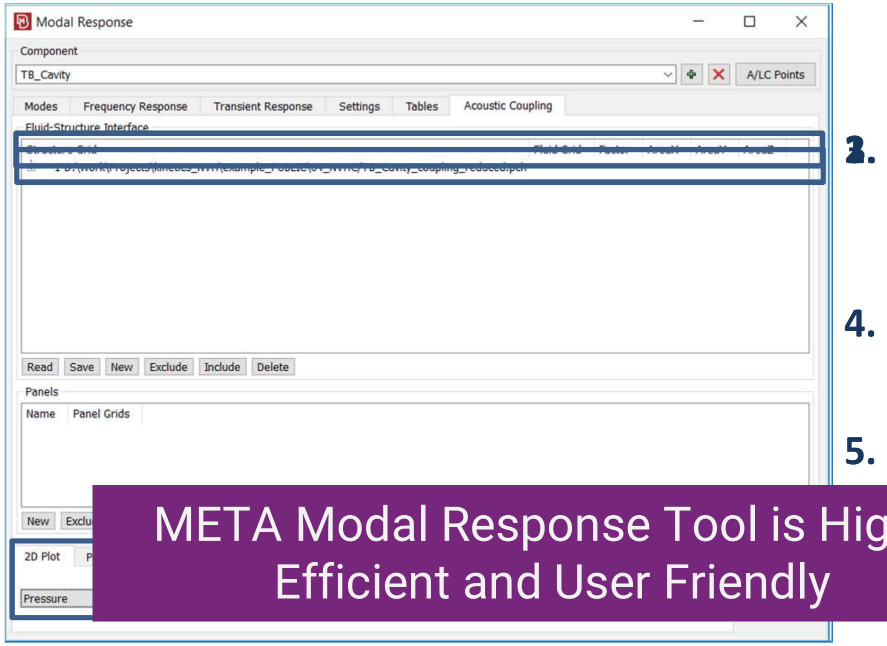
Fourier Transformation (FT):

- FT ≈ $t_s \cdot$ FFT
- Hanning window
- Zero-padding to increase df

ANSA PRE PROCESSOR   META POST PROCESSOR

- Python scripting in ANSA and META converts the calculated loads from MBS to Nastran loads
- NumPy package in BETA installation included
- Example: Frt Top Mnt forces for Sine Road
- Higher harmonics due to non-linearities?

Step 4: NVH Post Processing – Modal Response Tool



META Modal Response Tool is Highly Efficient and User Friendly

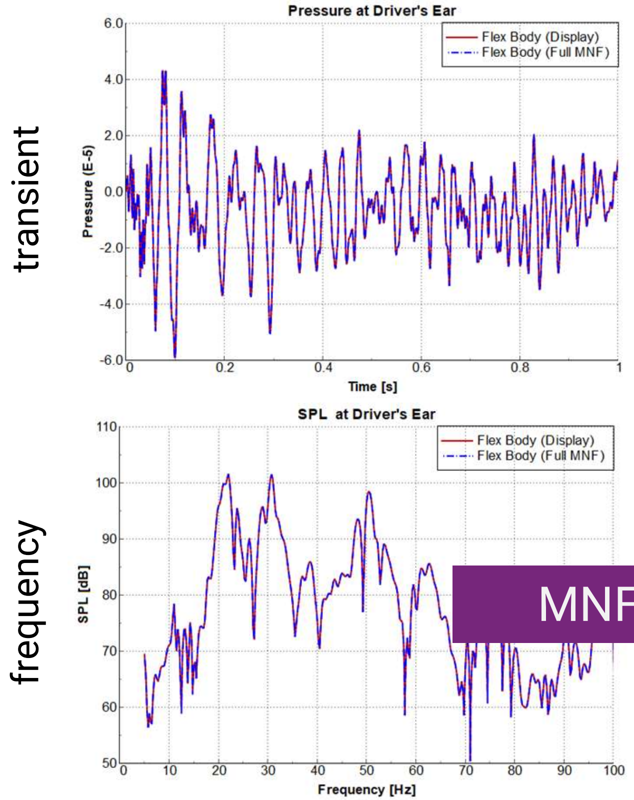
- BUT, transient acoustic response has not been implemented in Modal Response tool yet. It will be implemented in the near future!!
- Transient analysis for acoustic response shown here has been done with Nastran SOL112

META POST PROCESSOR

- Modal Response, Powerful NVH tool in META
  - 2D/3D transient and frequency response
  - Participation factors
  - Acoustic grid point participation
- Input:
  1. Modal result file
  2. FS-Interaction file
  3. Load case file
  4. Freq/time steps
  5. Response Dof
  6. Response type

Step 4: Results – MNF with Display

Pressure



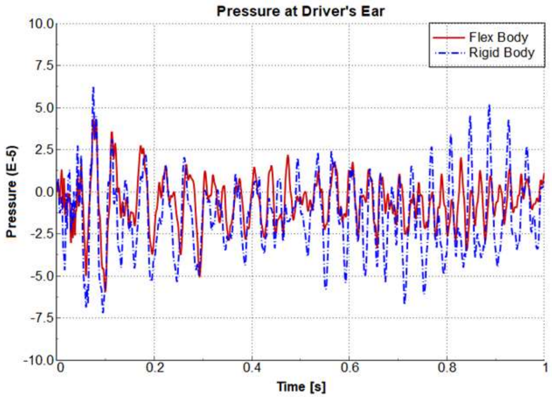
- Sine Road (26Hz)
- Transient and frequency results
  - pressure at microphone at Driver's Ear position (acoustic)
- Observation:
  - Full MNF = MNF with Display Model

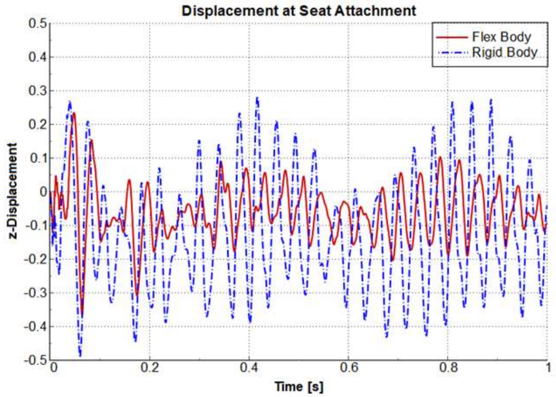
MNF Display Model is a Valid Approach

Step 4: Results – Influence of Flex Body

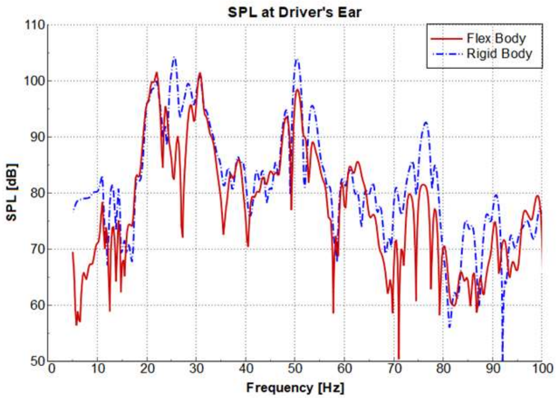
Pressure | Displacement

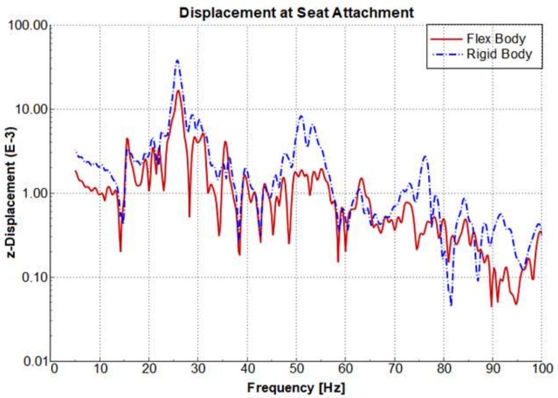
transient





frequency



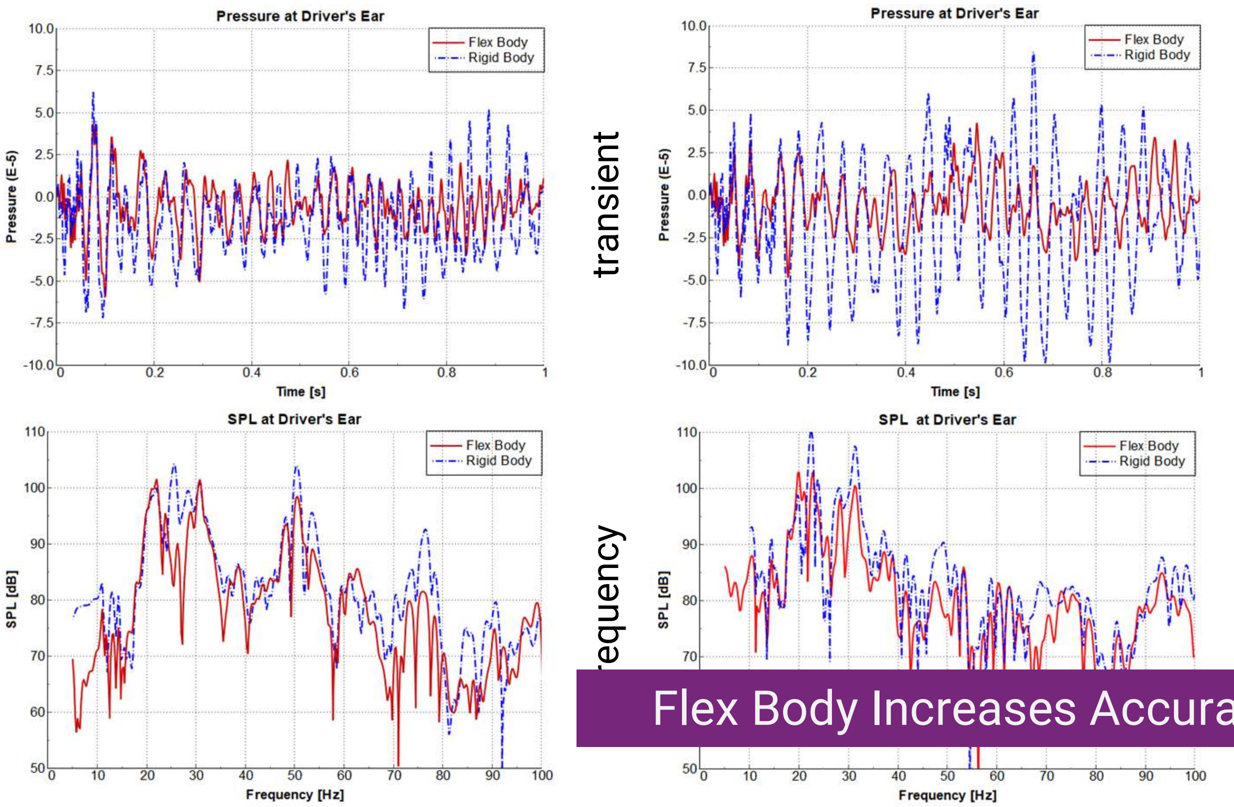


META POST PROCESSOR

- Sine Road (26Hz)
- Transient and frequency results
  - Pressure at microphone at driver's ear position (acoustic)
  - z-Displacement at seat attachment (tactile)
- Observation:
  - Rigid Body leads to increase responses

Step 4: Results – Influence of Flex Body

Sine Road (26Hz) Belgian Block

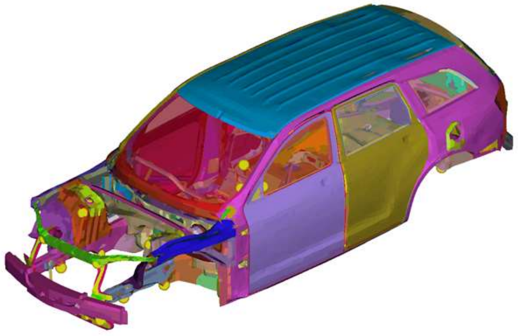


Flex Body Increases Accuracy of Results

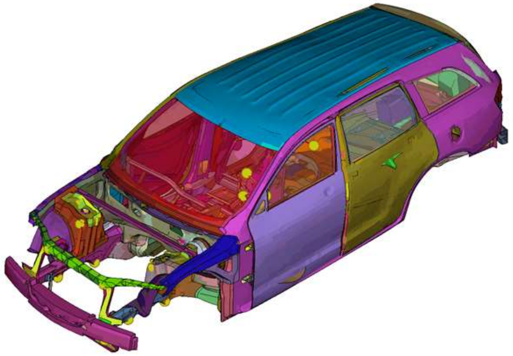
META POST PROCESSOR

- Sine Road (26Hz) and Belgian Block Road
- Transient and frequency results
  - Pressure at microphone at driver’s ear position (acoustic)
- Observation:
  - Rigid Body leads to increase responses

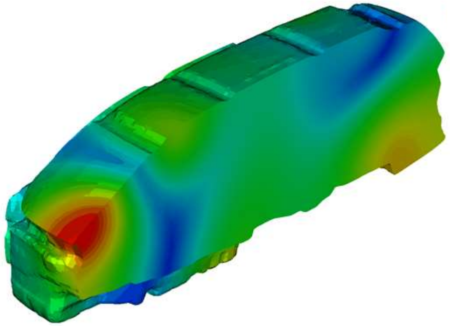
Step 4: Modal Response – 3D Animations



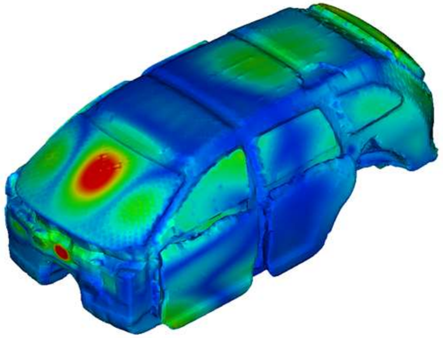
Transient Structural Response



Frequency Structural Response



Frequency Acoustic Response

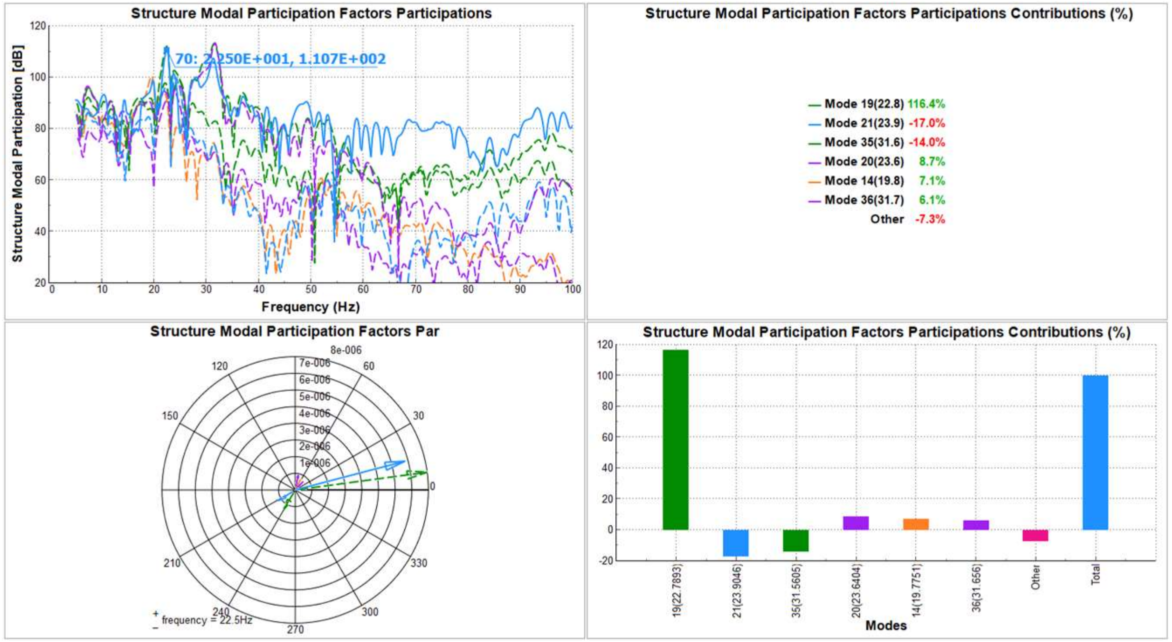


Frequency Grid Point Participation

META POST PROCESSOR

- 3D Animations in Modal Response Tool

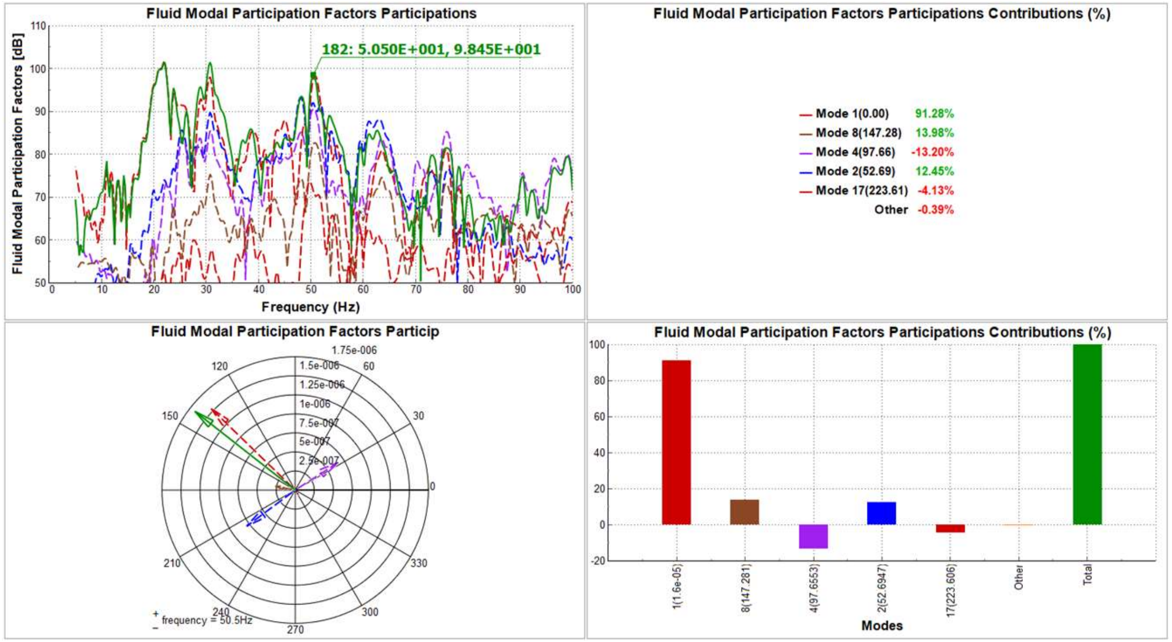
Step 4: Modal Response – Structural Modal Participation



META POST PROCESSOR

- Example:
  - Belgian Block Road, MBD Rigid Body
  - Structural modal participation
  - Main contribution to 22.5Hz peak in SPL: Global Torsion

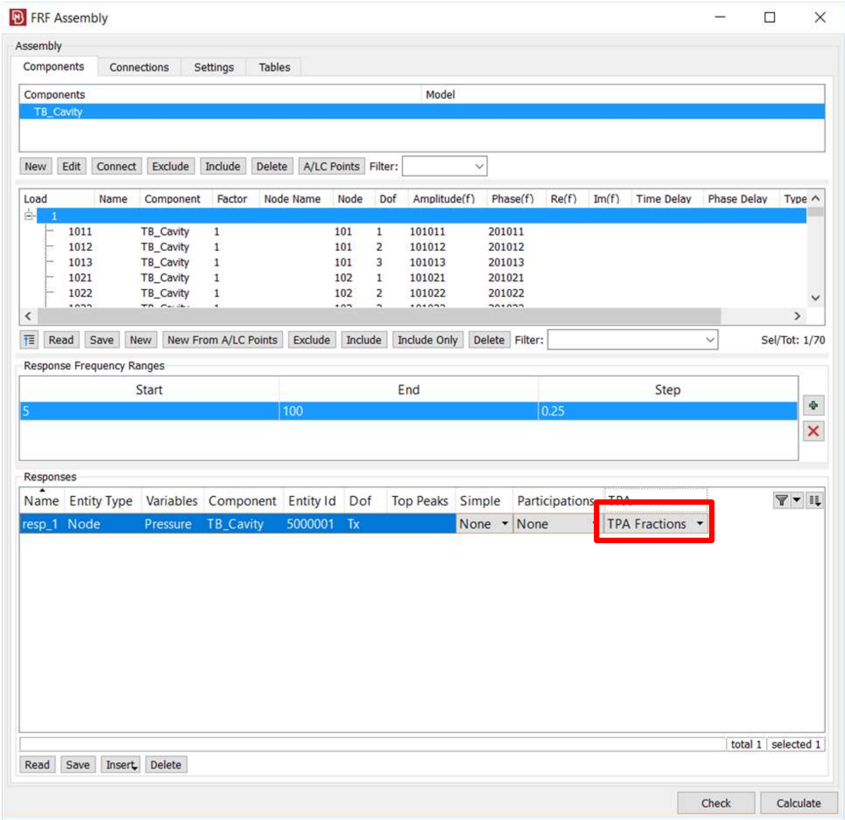
Step 4: Modal Response – Fluid Modal Participation



- Example:
  - Sine Road (26Hz), MBD Flex Body
  - Fluid modal participation
  - Main Contribution to 50Hz peak in SPL: Fluid rigid body mode

Easy Root Cause Analysis with Modal Participation

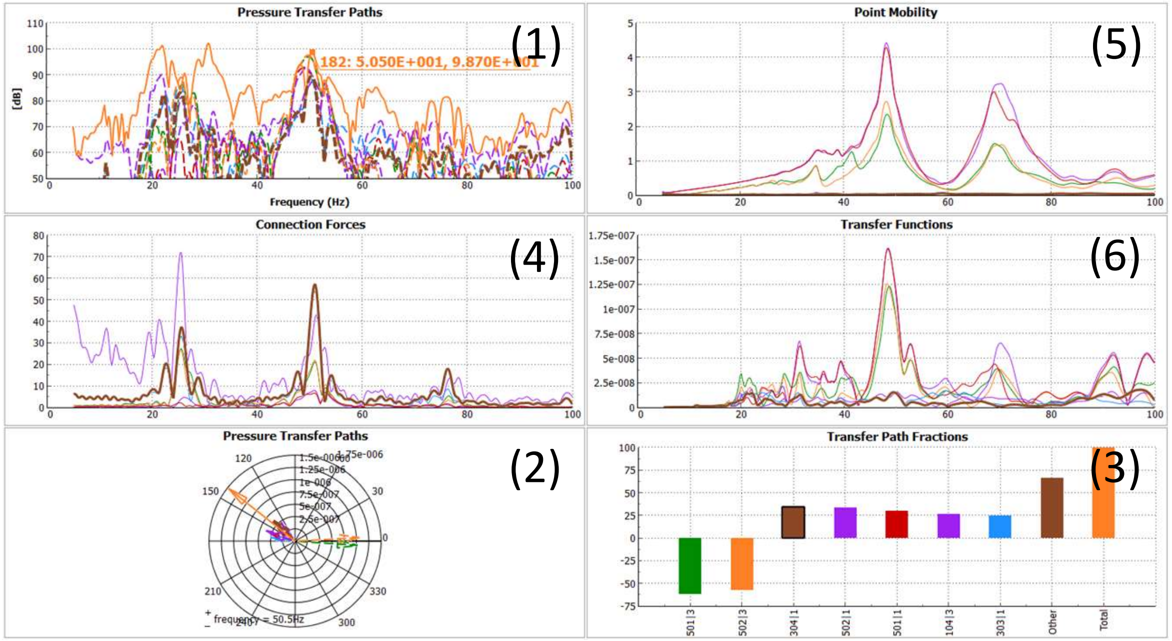
Step 4: FRF Assembly Tool - Transfer Path Analysis (TPA)



META POST PROCESSOR

- Advanced NVH analysis in META:
  - TPA in FRF Assembly Tool for any frequency response
  - Reveals which interface Dof and which force component causes mainly the response of the system

Step 4: Results – Transfer Path Analysis



Detailed Root Cause Analysis with TPA

META POST PROCESSOR

- Example:
  - Sine road (26Hz), MBD Flex Body
  - 50Hz peak in SPL
- TPA Tool displays for N top contributing paths:
  - Path participation
    - Absolute (1)
    - Complex (2)
    - Fraction (3)
  - Forces (4)
  - Point Mobility (5)
  - Transfer functions (6)

Conclusions/Summary

Summary/Results

- A seamless process, completely inside the BETA Suite, was presented using forces from a Non-Linear MBD analysis to calculate NVH related responses on a Trimmed Body
- Using forces calculated with Flex Bodies instead of Rigid Bodies in the MBD simulation has a significant effect on the NVH results
- Utilizing a Display Model during the NVH analysis AND for the MNF file calculation leads to feasible file sizes and especially facilitates the application of Flex Bodies in the MBD simulation
- META NVH tools enable efficient root cause analysis methods

Identified Areas for Tool Improvements

ANSA Kinetics

- Automatic creation of transient and frequency load case (including all necessary options for FT) to avoid scripting solution

META

- Calculation of transient acoustic response
- Modal participation for transient response

Implementation Depends on Customer's Request/Interests in this Process!

Outlook - Advanced Processes/Applications

Advanced Models

- MBD model with more than one Flex Body, e.g. Subframes also as Flex Bodies
- Linear NVH model with more than one component, e.g. TB and IP separated
  - Coupling of components with FRF assembly or CMS in Epilysis
  - Easy set-up in NVH-Console

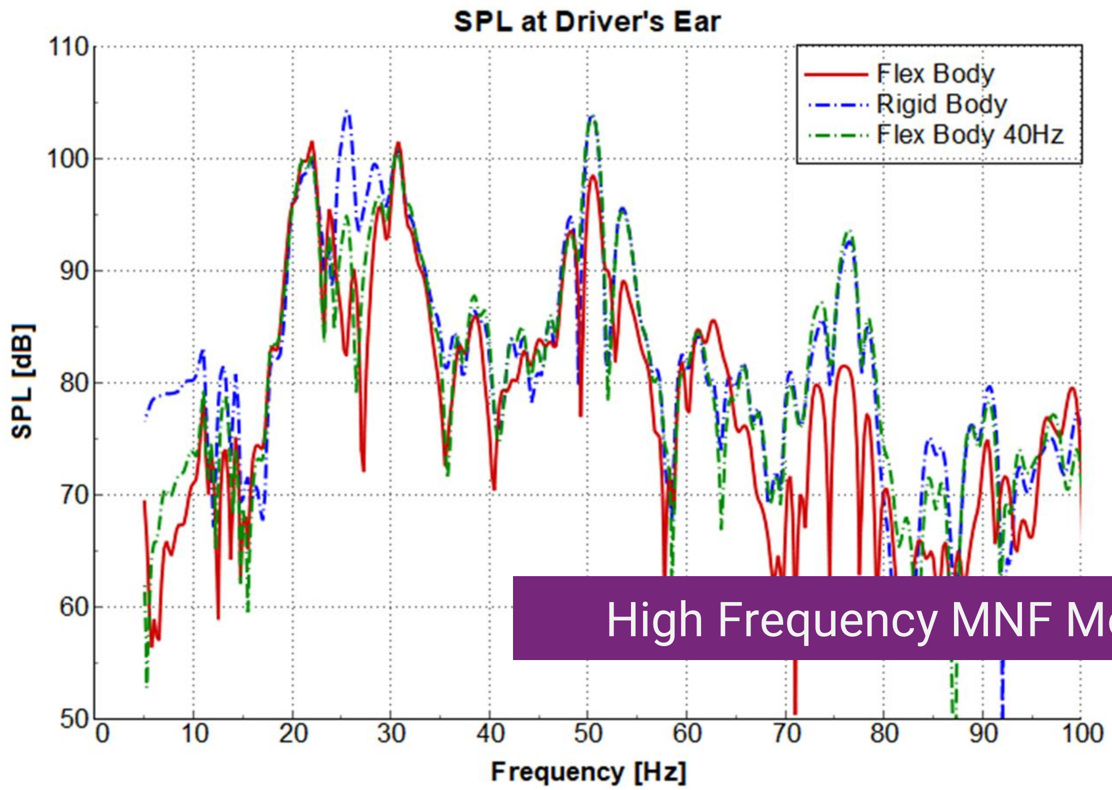
Automated Process

- Scripting capabilities in ANSA/META enable automatization and set-up of optimization loops

Stay connected

Backup Material

Results – Influence of Constrained Modes

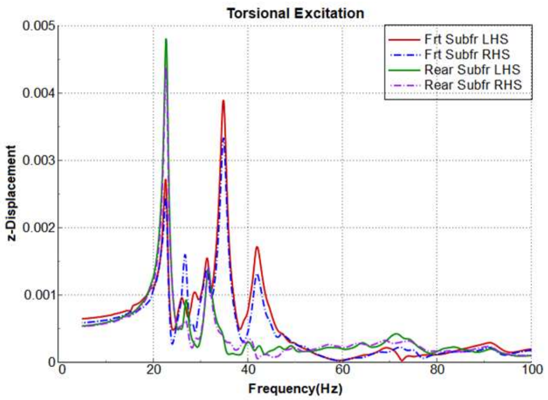


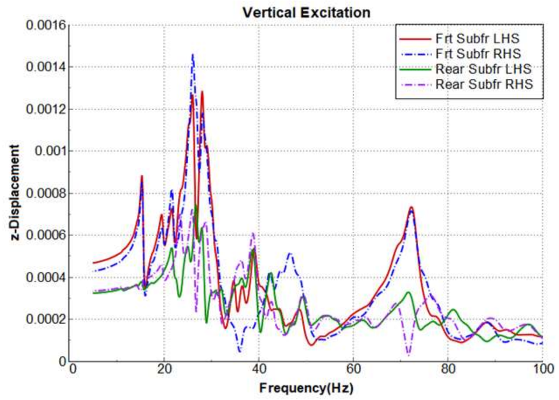
High Frequency MNF Modes are Important

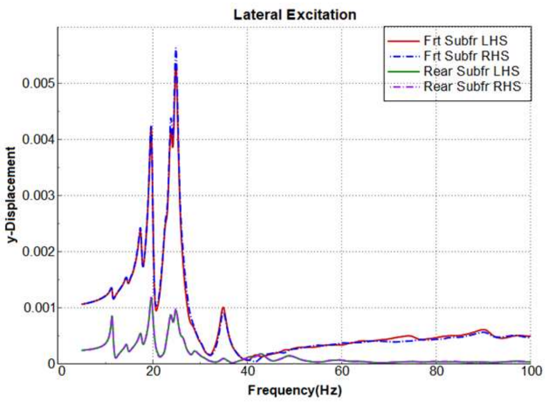
META POST PROCESSOR

- Example:
  - SPL for sine road

Results – Identification of Global Modes





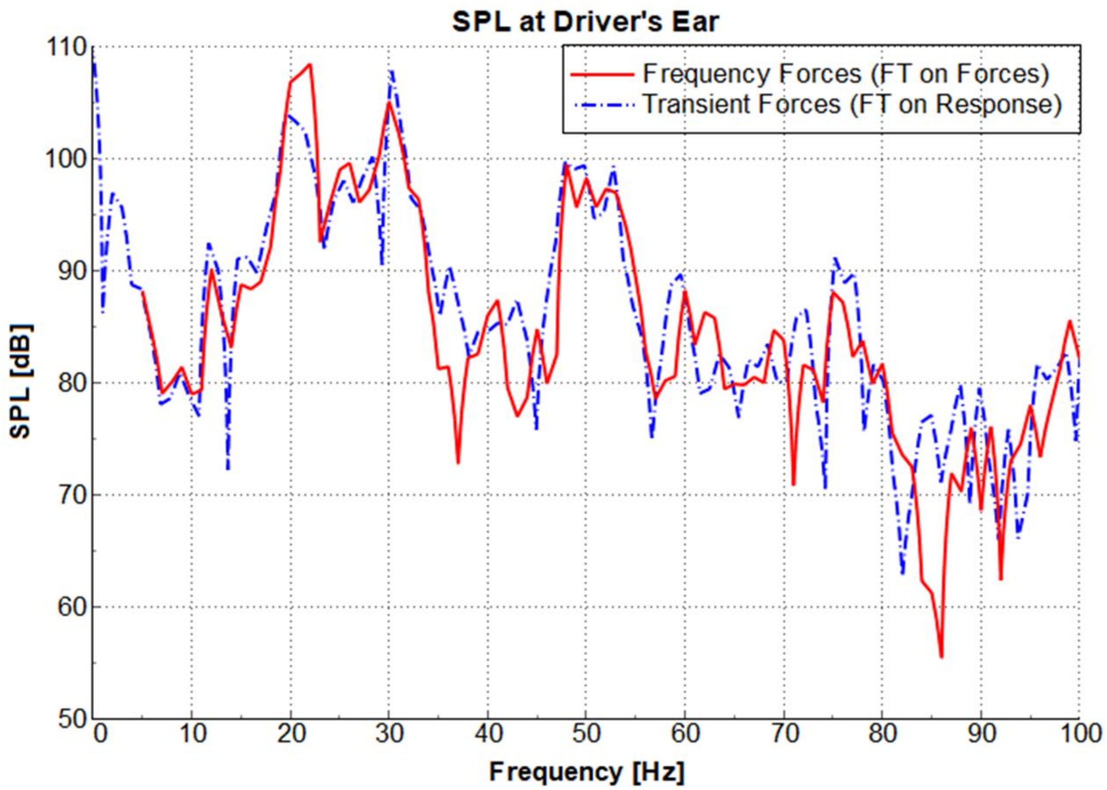


	1. Mode [Hz] (no)	2. Mode [Hz] (no)	3. Mode [Hz] (no)
torsion	22.8 (19)	34.9 (39)	41.7 (54)
lateral	19.6 (15)	24.9 (23)	34.9 (39)
vertical	26.1 (26/27)	28.2 (28)	72.2 (135)

META POST PROCESSOR

- Global modes are identified by torsional, lateral and vertical dynamic loads
- Main peaks reveal the global modes frequencies
- Modal participation analysis reveals the global mode numbers

Results – Commutability of System Response and FT



- FT on transient response is similar but not identical as frequency response due to FT of forces!
- Possible root cause: Different damping mechanism in frequency and time domain