LMS/SYSNOISE 功能簡介

System for Vibro-Acoustic Analysis

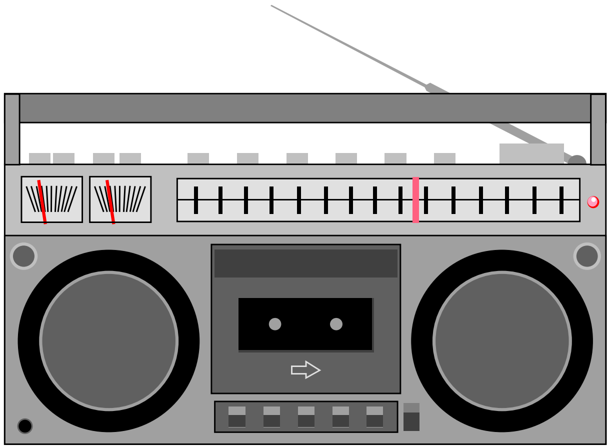
LMS Numerical Technologies

A Few Words About Acoustics

Source

vibrating body

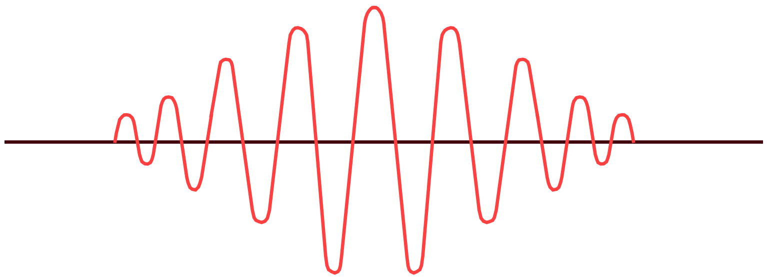
speaker



Propagation

sound path & absorption

- airborne
- structure-borne
- mixed



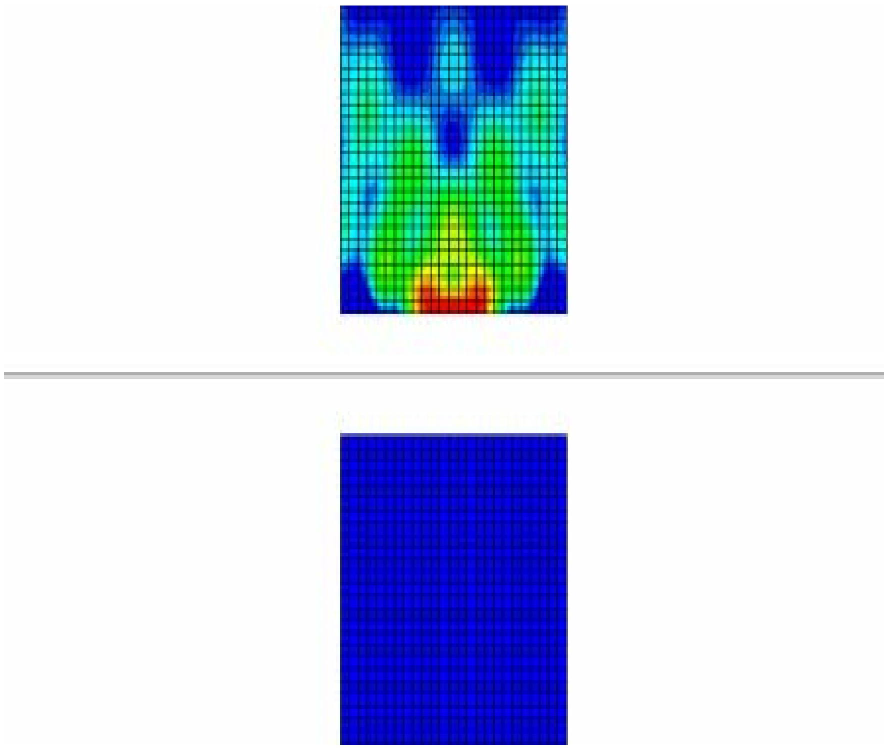
Receiver

microphone

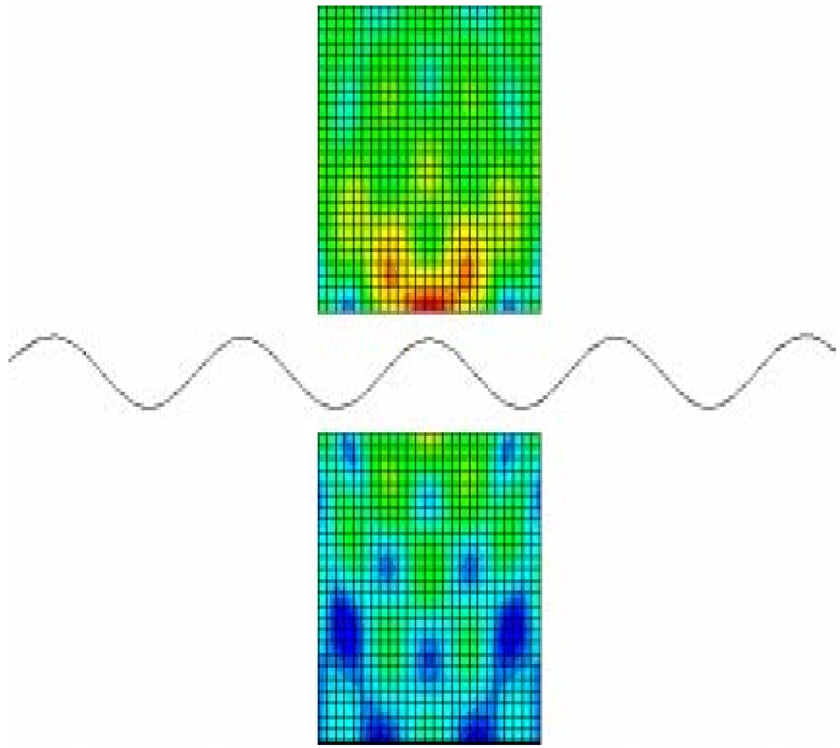
ear

Dealing with Vibration & Sound

Rigid wall

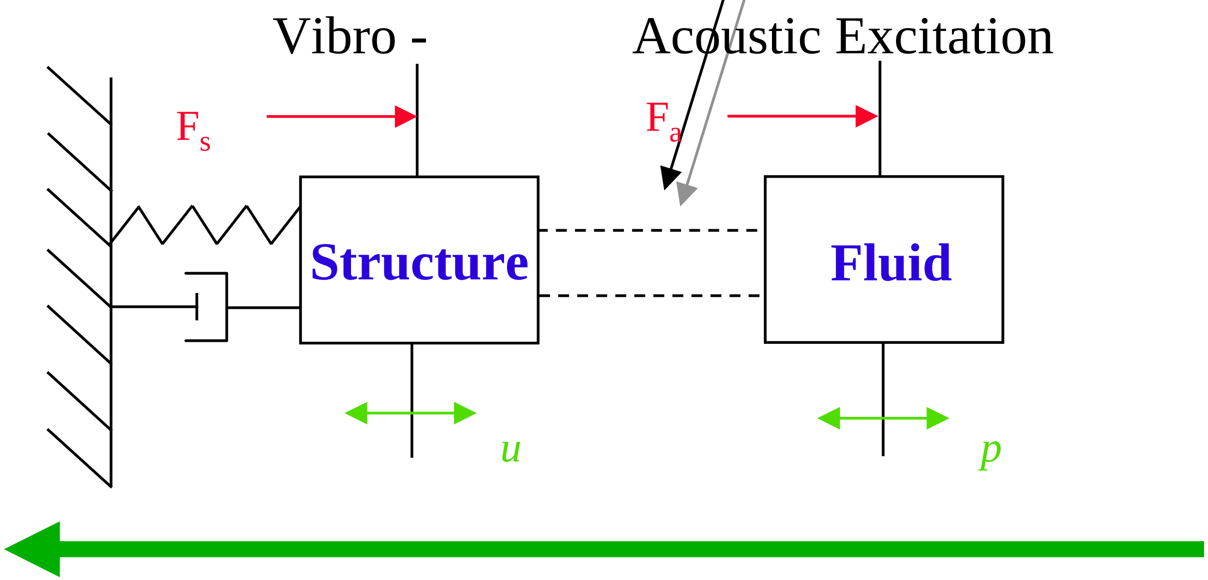


Flexible wall



Fluid-Structure Coupling

Vibration generates Sound



Sound induces vibration

Harmonic vs Transient Analysis

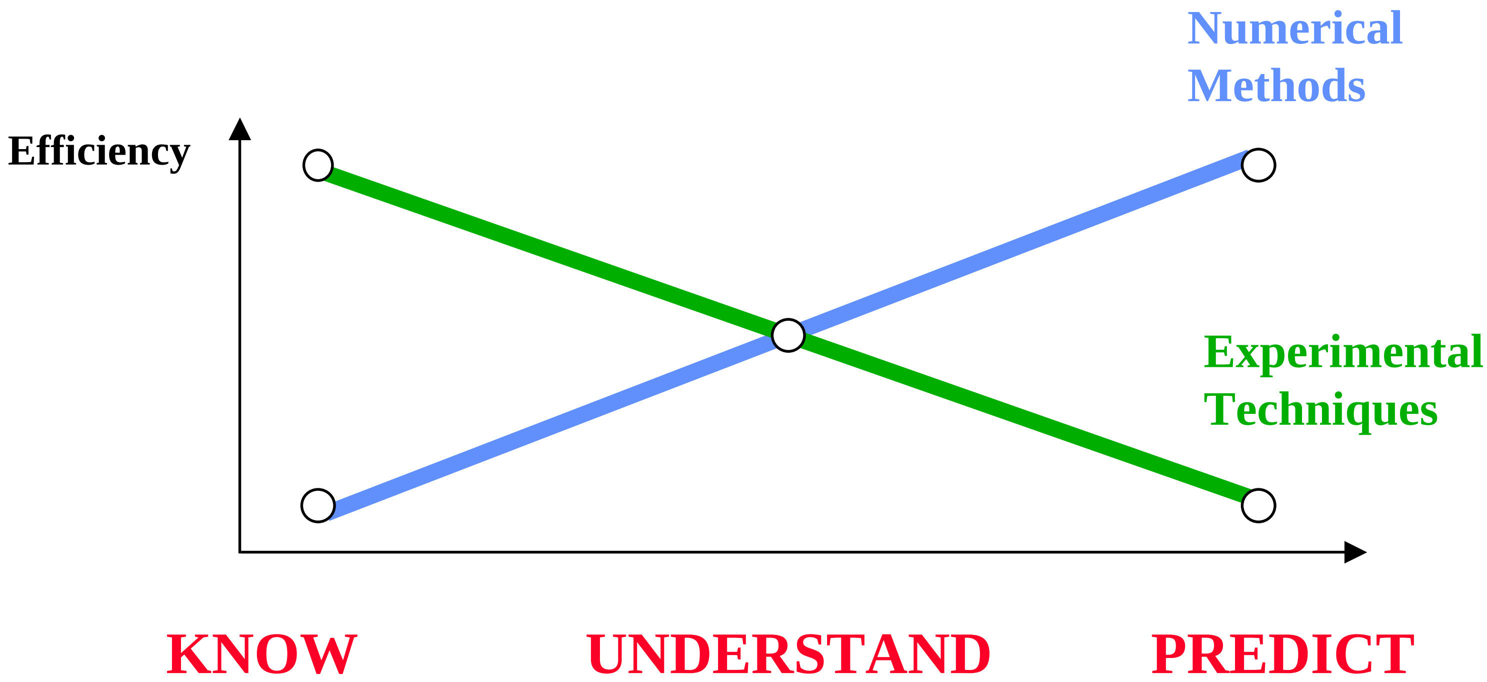
- **Frequency** domain
  - **Helmholtz** equation
  - Harmonic or narrow-band excitations
  - Solution with **complex** variables

$$\nabla^2 p + k^2 p = 0$$

- **Time** domain
  - **Wave** equation
  - Transient (e.g. shock)
    and broad-band excitations
  - Solution with **real** variables

$$\nabla^2 p = \frac{1}{c^2}\frac{\partial^2 p}{\partial t^2}$$

Why Numerical Simulation ?



Usual Numerical Tools

0 (Semi-) **Analytical Methods**

- 4 Closed form solutions
- 4 Only for simple geometries

0 **Finite Element Method (FEM)**

- 4 Volume discretization into Finite Elements

0 **Boundary Element Method (BEM)**

- 4 Dicretization of bounding surface into Boundary Elements

0 **Statistical Energy Methods** (SEA)

- 4 Energy exchanges between system components

0 **Ray Methods**

- 4 Geometrical Acoustics
- 4 RAYNOISE, MOSART

Why Acoustic Analysis ?

- **Acoustics** becomes increasingly important
  - Product **quality**
  - Competitive advantage
  - Part of design specifications
  - Government **regulations** quality of Life
- **Analysis** up-front in the design phase
  - Concurrent engineering
  - Early **interaction** with design engineers
  - Evaluate design **alternatives**
  - Reduce **prototyping**
  - Significant **cost** and **time savings**

Typical Acoustic Analysis

- Sound **radiation** from vibrating structures
- Acoustic **reflection** and **diffraction** of sound waves
- Sound **transmission** between fluid regions separated by a structural partition

- **Acoustics**
  - Fluid behavior only
  - Boundary conditions
    - panel velocities
    - sound sources
    - panel absorption
- **Vibro-acoustics**
  - Interactions between structure and fluid
  - Coupled response
    - structural vibration
    - acoustic pressure

Why SYSNOISE ?

0 Most **mature** and **complete** interactive solution today

0 The user has the **right to choose** his method

  4 FEM or BEM

  4 Direct or indirect

  4 Coupled or uncoupled

  4 Transient or harmonic

0 Developed for **power users** as well as **occasional users**

0 **Compatible** with

  4 your **hardware environment**

    8 UNIX, CRAY, CONVEX, IBM SP2 and Windows platforms

  4 your **software investments**

    8 FE packages, TEST softwares (LMS CADA-X)

SYSNOISE Offers You ...

0 **Modeling facilities (economy of time)**
  4 Automatic mesh checking and coarsening
  4 Optimized solvers for all methods
  4 Non-linear matrix interpolation

0 **Fully Interactive** analysis
  4 Graphical user interface
  4 Wizards
  4 Customizable environment

0 **Minimum memory** requirements

0 **Maximum speed** for calculation

0 **No inherent limit**
  4 Dynamic memory allocation
  4 Out-of-core procedures for all the solvers

Methods & Frequencies

Acoustics

SYSNOISE	MOSART, RAYNOISE

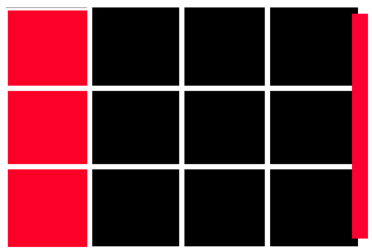
Vibro-Acoustics

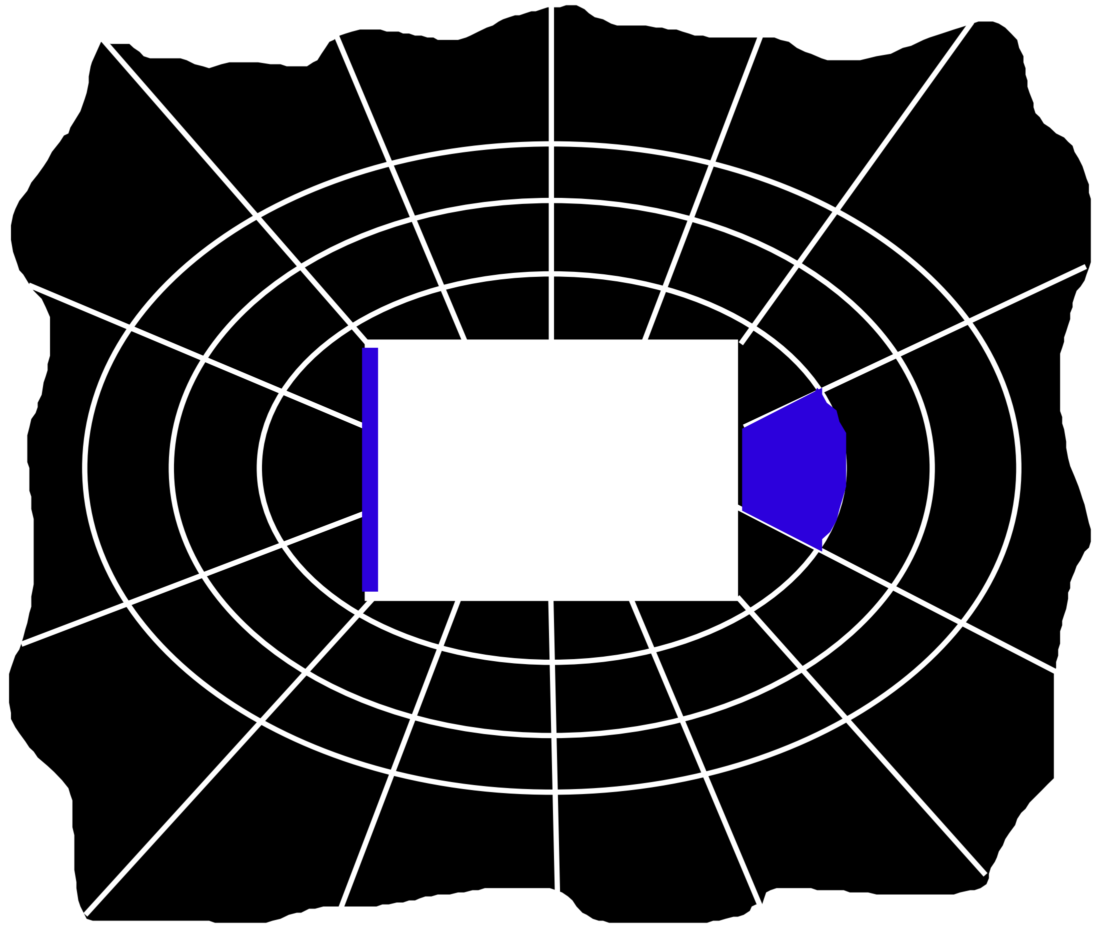
SYSNOISE	SEA

→

higher frequency
higher modal density

FEM & I-FEM

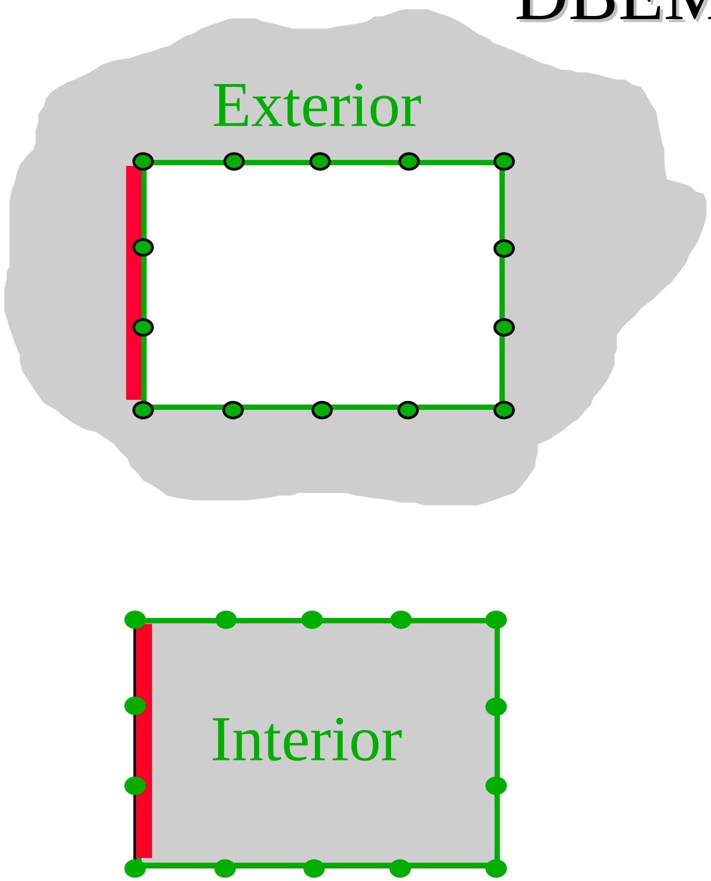




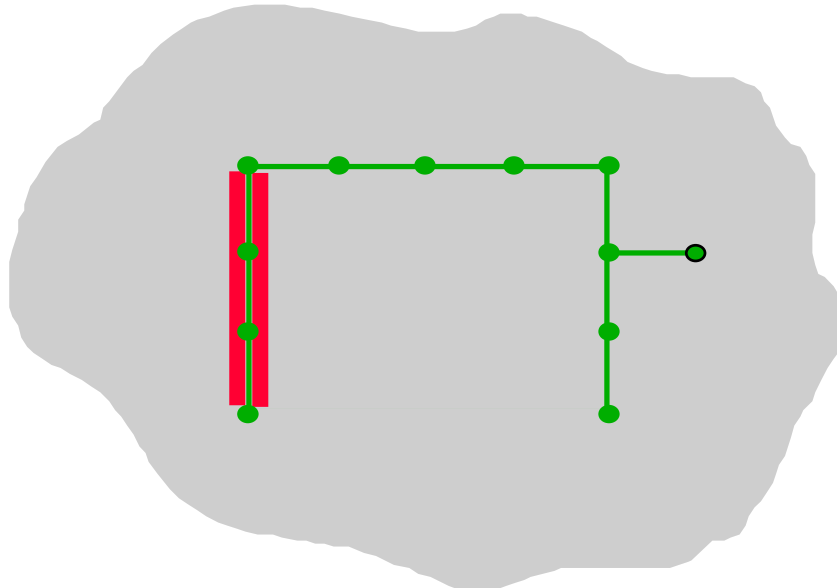
- interior/exterior domain
- volume mesh : slower
- heterogeneous or homogeneous fluid
- volume/surface absorber
- solution : fast

BEM

DBEM

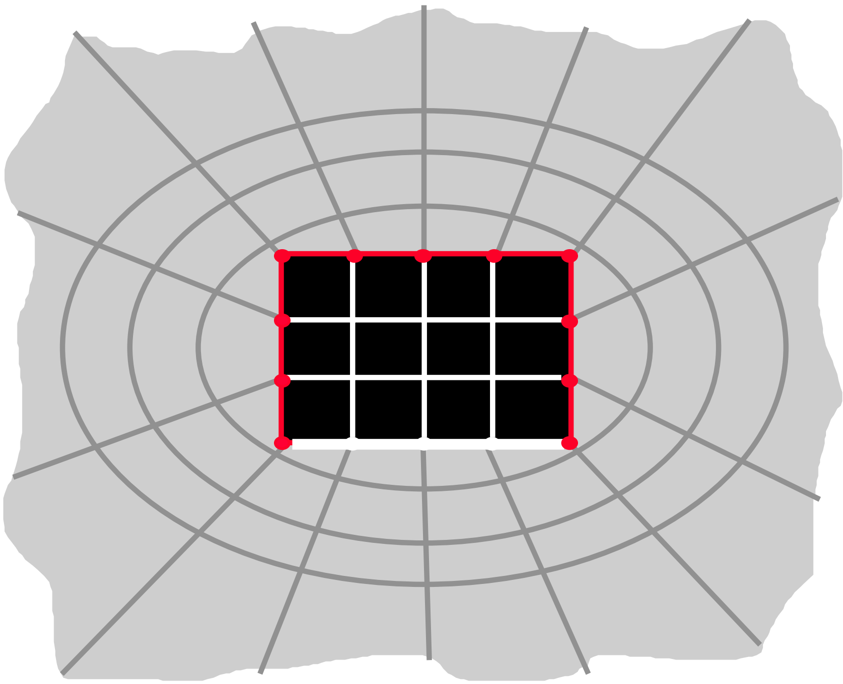


IBEM

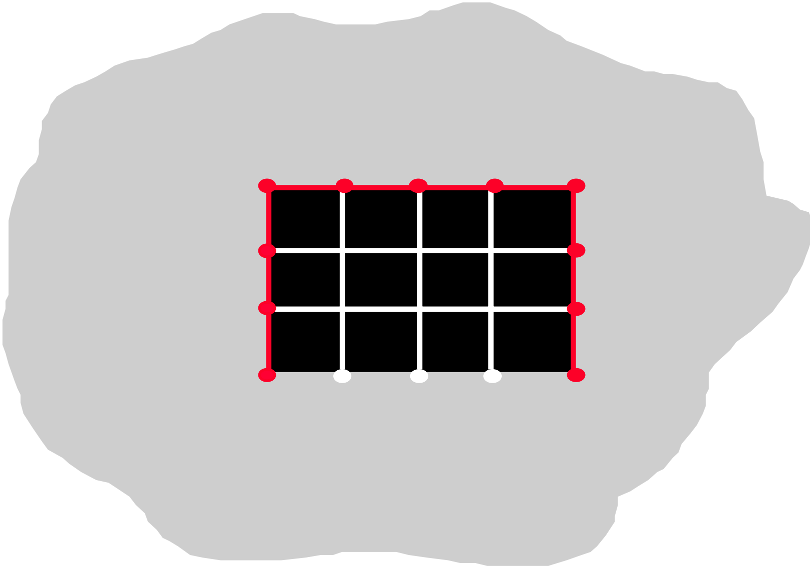


- 0 homogeneous fluid
- 0 surface absorbers
- 0 meshing : faster

Multi-domain methods

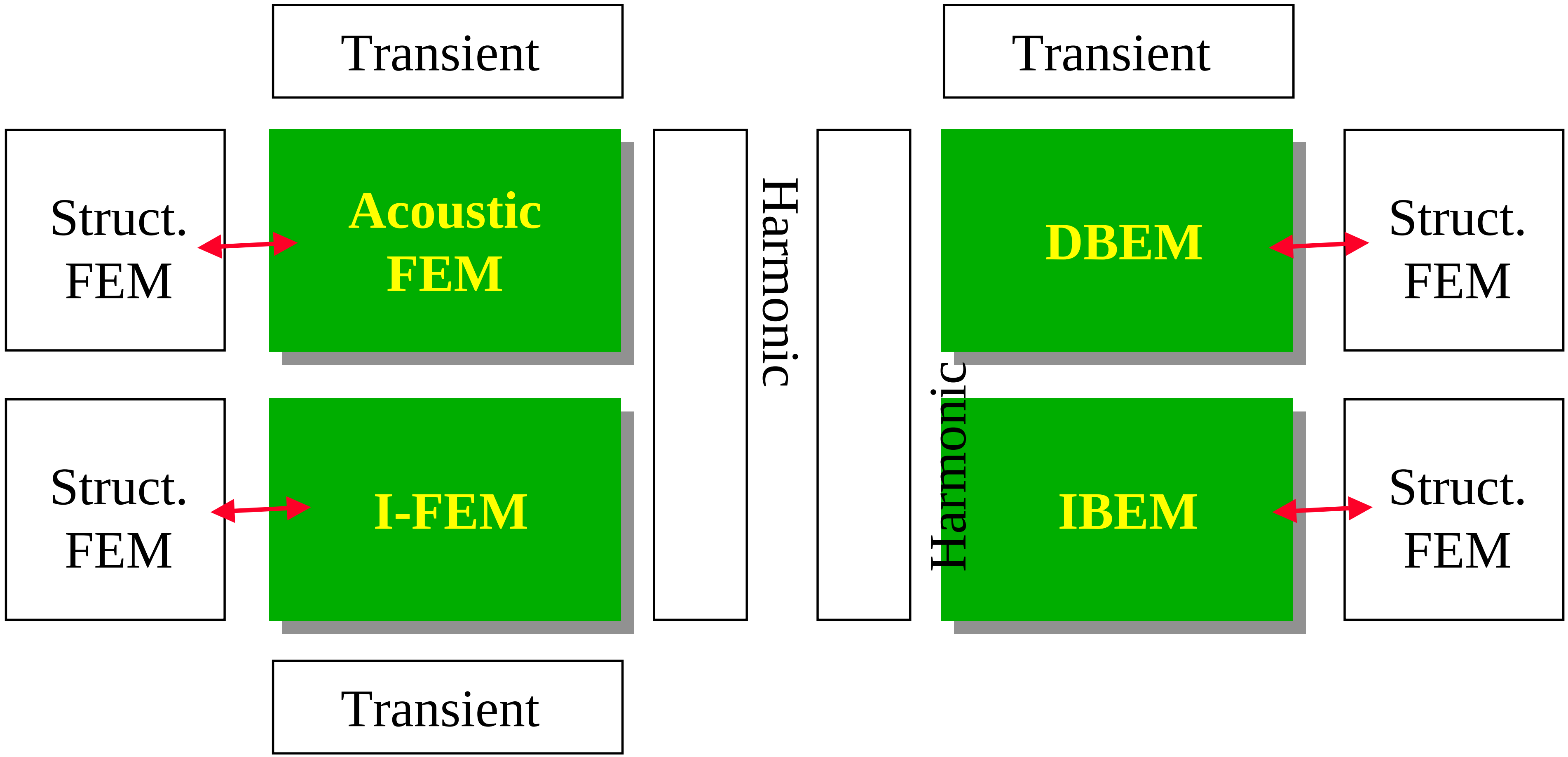


FEM + I-FEM

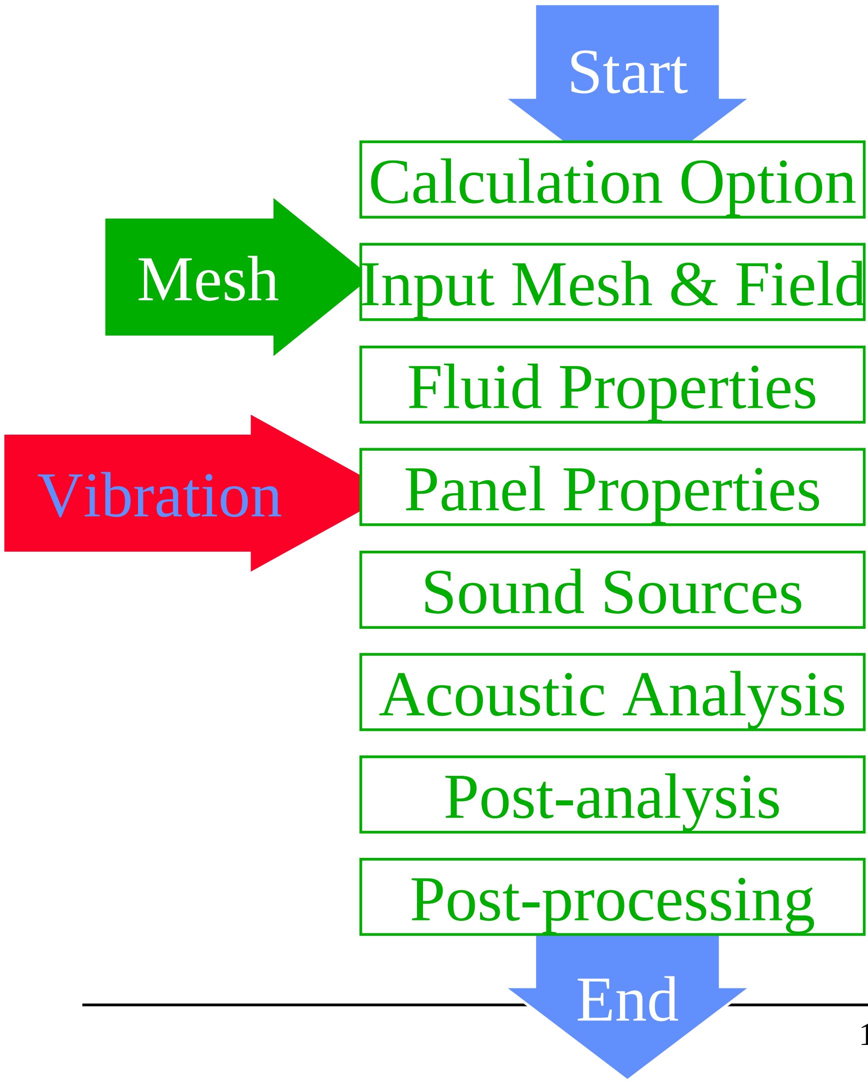


DBEM or FEM + DBEM

Available Modules of SYSNOISE



Calculation Sequence



e.g. FEM or BEM

Mesh checking & correction

Density and speed of sound

Structural and absorption properties
Panel velocities or nodal forces

Spherical, Planar, User

Modes, Response, Matrices

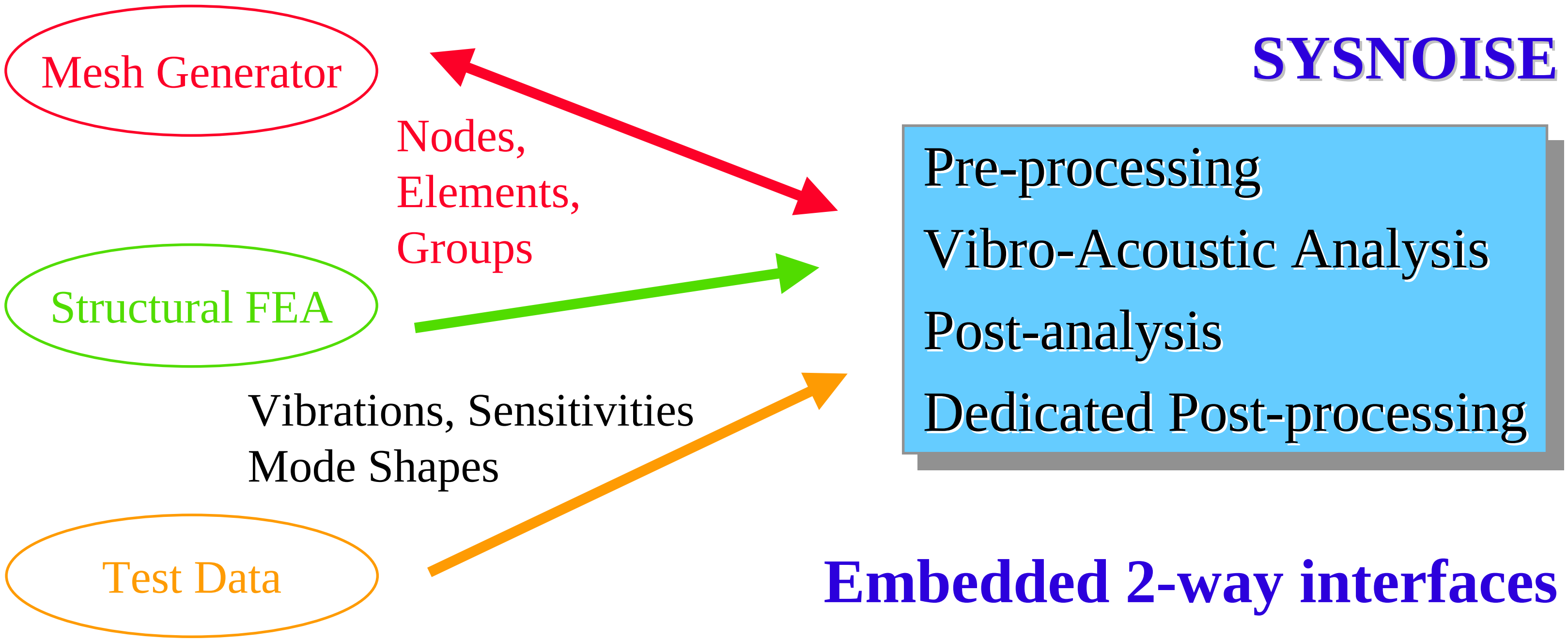
Directivity, Contribution, Sensitivities

XY, Contours, Vectors, Animation

Vibration Input

- From **FEA**
  - Uncoupled (acoustic) analysis : **vibration patterns**
  - Coupled (vibro-acoustic) analysis : str. **normal modes**
- From **Test** (coupling effects included)
  - Accelerometer or laser **measurements**
  - Sorted per frequency or per measurement location
- **Manual** input
  - **constant** velocity over the considered frequency range
  - through **frequency dependent** tables

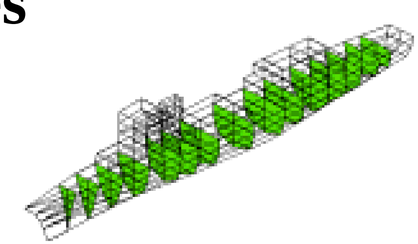
Available Interfaces

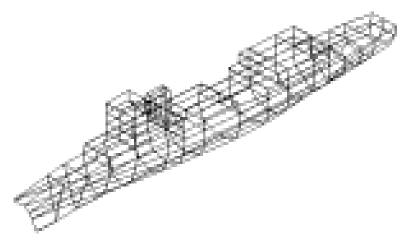


- MSC/NASTRAN - MSC/PATRAN
- LMS/CADA-X
- ANSYS
- I-DEAS Master Series
- Hypermesh
- ABAQUS
- MARC
- ProMechanica
- FemGen/FemView
- SYSTUS

Pre-processing

- **Import** meshes from external mesh generators
- Mesh **checking** and **coarsening**
- Automatic **search** and **handling** of **junction** lines
- Automatic **search** and **handling** of **free edges**
- Visual creation of item **groups**
- Application of **boundary conditions**
  - panel absorption
  - panel vibration
  - acoustic sources



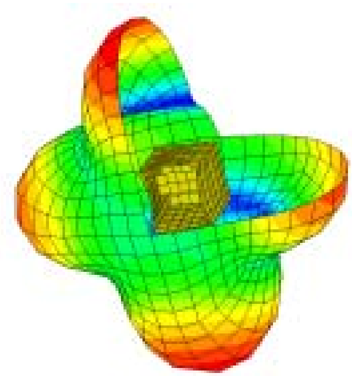


Vibro-Acoustic Analysis

- **Normal modes**
  - **Acoustic** mode shapes
  - **Structural** mode shapes (fluid loaded)
- **Vibro-Acoustic response**
  - Acoustic (and structural) results at nodes and field points
    - **uncoupled** and **coupled** analysis
    - **transient**, **harmonic** and **random** (BEM) solution
    - automatic **out-of-core** solvers for all modules
- **Matrices**
  - Compute and export FE and BE matrices
  - Added mass matrix

Post-analysis

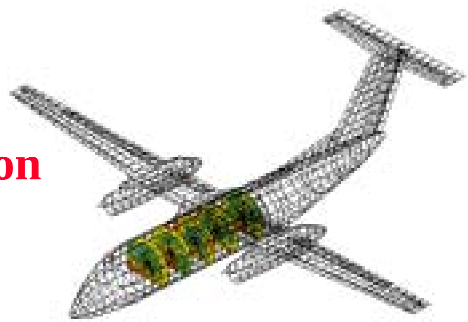
- **Directivity**
  - **polar** diagrams
  - **3D** balloons



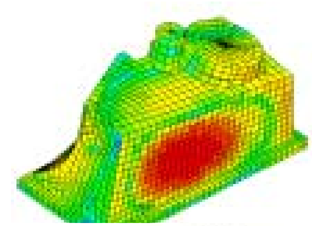
- Panel **Contribution**
  - **contribution** to sound pressure or sound power
  - **total** or **effective** contribution
- **Sensitivities**
  - structural and acoustic design variables
  - **global** and **acoustic** sensitivities

Dedicated Post-processing

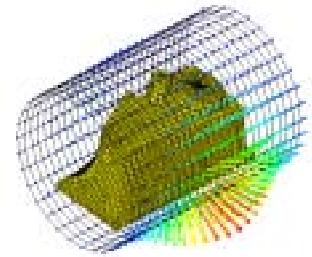
- **XY** plots
  - time and frequency dependent **response functions**
  - **weighted** or not (dBA, B, C...)
  - narrow band, octave, 1/3 octave
- **Polar** diagrams
  - sound **directivity**
  - complex **contribution**
- **Bar** charts
  - panel **contributions**
  - modal **participation** factors
  - **sensitivities**



- **Contour** plotting
  - **pressure**
  - **vector field** components



- **Deformed** geometry



Vector diagram
  - superimposed meshes
  - velocities, intensitities, ...

Animation
  - **transient** response
  - **frequency** scanning
  - **phase** animation

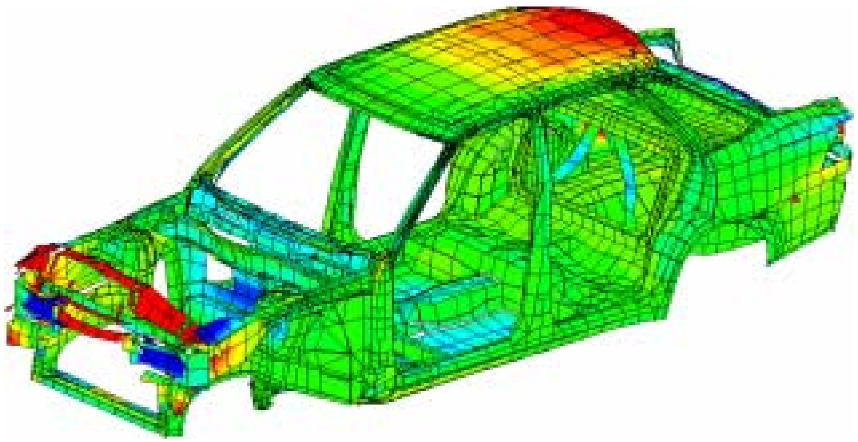
Conclusion

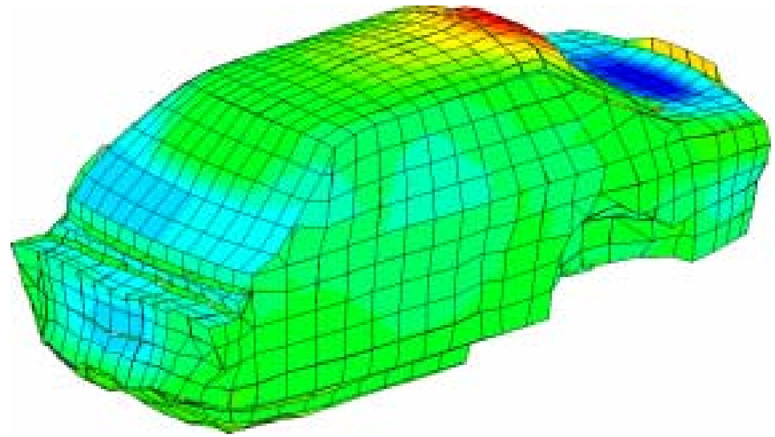
- **SYSNOISE is the leading software** for computational vibro-acoustics
- **SYSNOISE** offers you a **broad choice of methods**
  - to predict **sound** from vibrating structures
  - to simulate the **interaction** between fluid and structure
  - to optimize acoustically your **product design**
- **Main benefits** of using **SYSNOISE**
  - Integrated software
  - Ease-of-use
  - Calculation speed
  - Open architecture
  - Customization
  - All major computers

LMS/SYSNOISE 應用實例

- 內部聲場
- 外部聲場
- 流場結構互動
- 設計改善
- 汽車
- 航太
- 家用產品

車內噪音分析





Body Noise Transfer Functions

0 **Interior** Noise Prediction using **Acoustic BE** Analysis

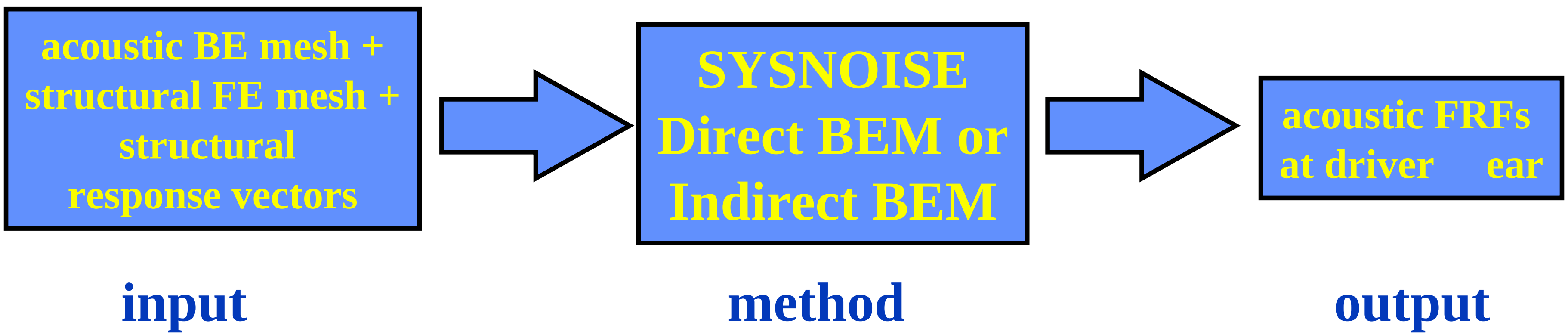
0 Analysis of **Structure-Borne** Noise

  4 structural excitation

  4 acoustic response

    8 frequency dependent pressure

    8 at driver ear



Definition of BNTF

0 **What ?**

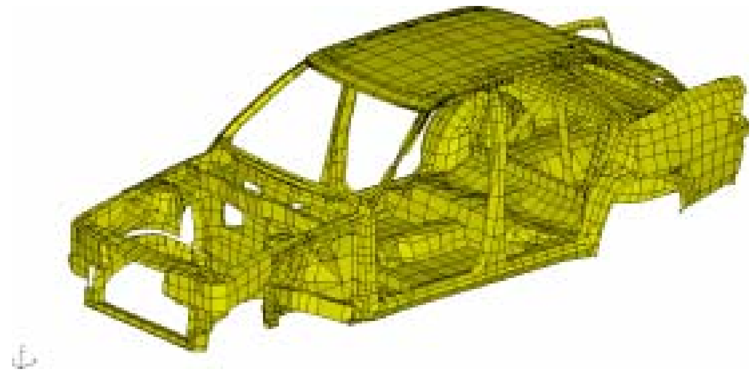
- 4 frequency response function
- 4 of sound pressure at a field point
- 4 caused by a unit force
- 4 at a structural excitation point
  - 8 engine mount
  - 8 suspension point

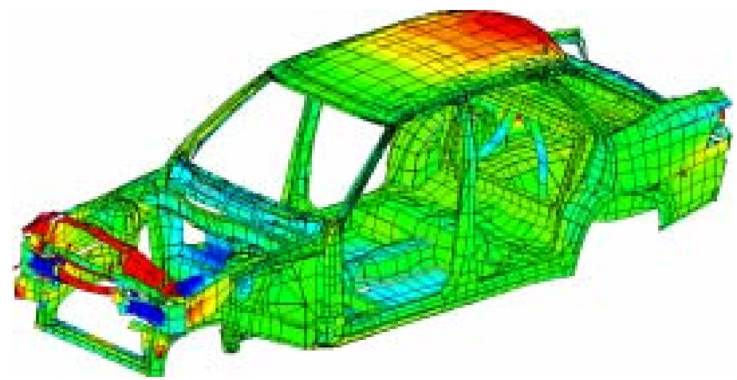
0 **Why ?**

- 4 **if same car body and same acoustic compartment**
- 4 **but different engines, suspension systems**
- 4 **you can use the same BNTF !**

First Step = Structural FE Analysis

- **Structural FE Mesh**
  - 8914 nodes, 11086 elements
  - body in white
- **Excitation**
  - Unit force (engine mount)
- **Analysis**
  - Normal modes (up to 120 Hz)
  - Modal superposition
- **Results** = **Body displacements**
  - from 5 to 70 Hz, step 1 Hz
  - usually limited to 100 ... 150 Hz





Model Courtesy of Daewoo

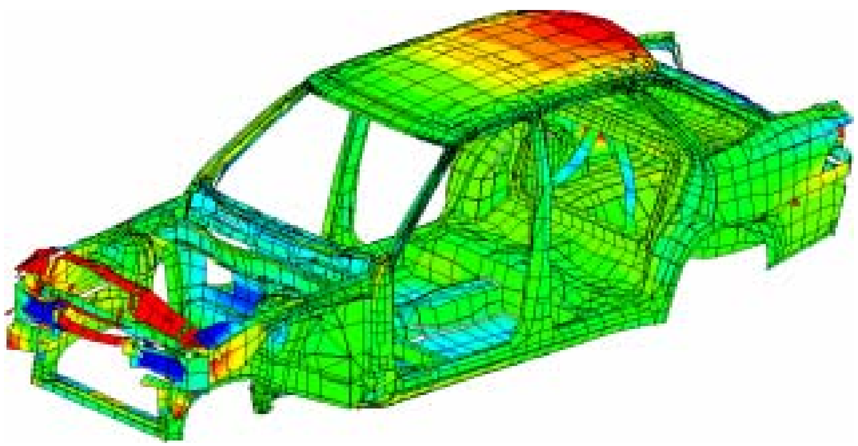
Second Step = Acoustic BE Analysis

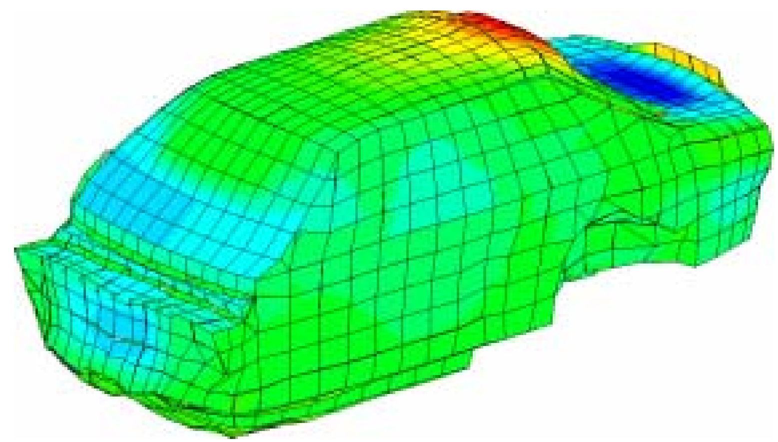
0 **Incompatible Meshes**

- 4 acoustic BE mesh with only 1168 nodes and 1200 elements
- 4 different wavelengths for fluid and structure (bending)
- 4 different geometries and different element densities

0 **Automatic Multi-Frequency Transfer**

- 4 structural displacements => normal acoustic velocities

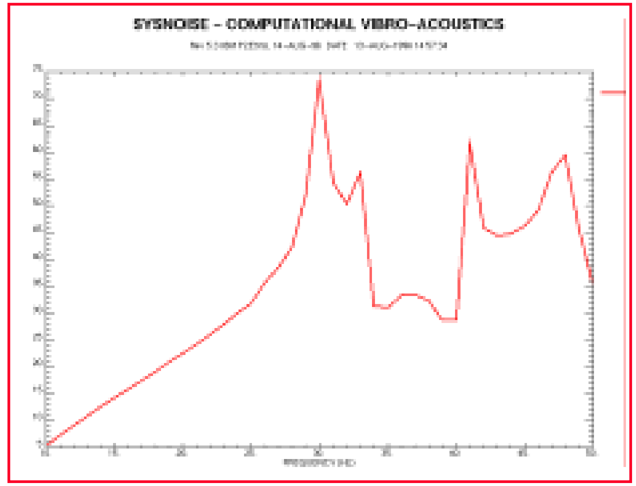




Acoustic Response Calculation

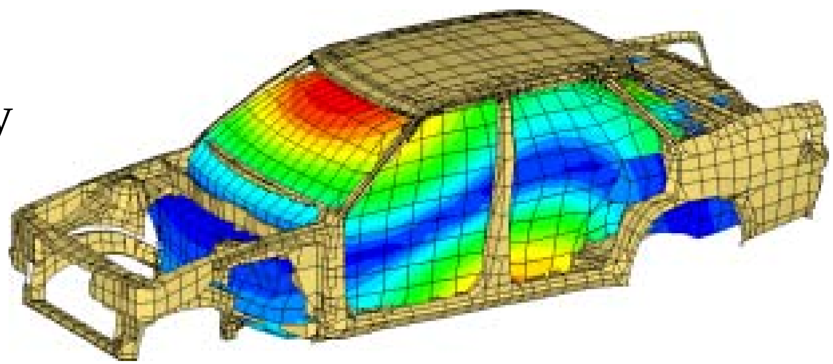
0 **Acoustic Frequency Response Function (Field Point)**

- 4 driver ear
- 4 pressure (dB)
- 4 all frequencies



0 **Acoustic Field (Field Point Mesh)**

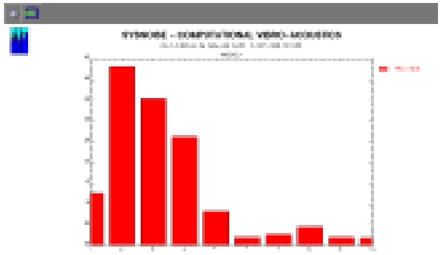
- 4 whole cavity
- 4 pressure (dB)
- 4 one frequency



acoustic calculation time negligible compared tostructural analysis

Conclusion

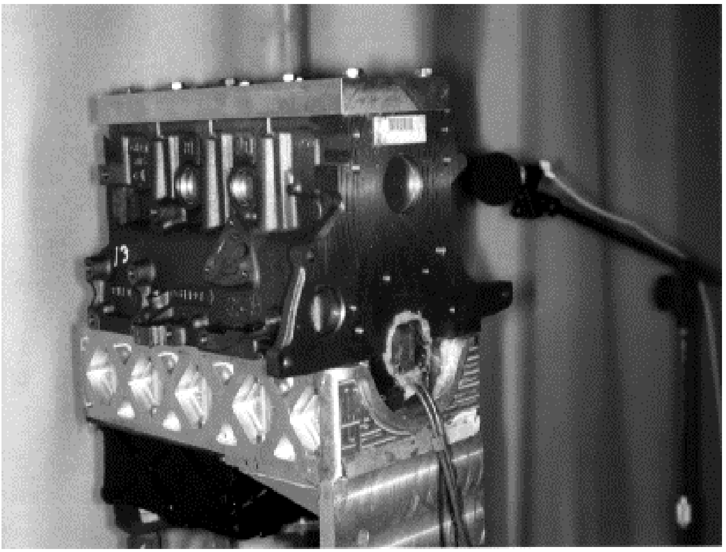
- Driver ear response computed with **SYSNOISE**
- Further information may be obtained from a **contribution analysis**



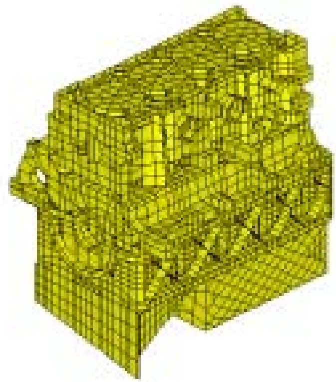
Contribution

- A tool for each problem
  - low frequency (Vibro-)Acoustics : SYSNOISE
  - medium to high frequency Acoustics : MOSART
  - high frequency (Vibro-)Acoustics : SEA
- Interface to **Sound Quality Monitor** (LMS CADA-X)
- Equivalent results between acoustic FE and BE
- **Very fast acoustic calculation**

引擎本體輻射噪音

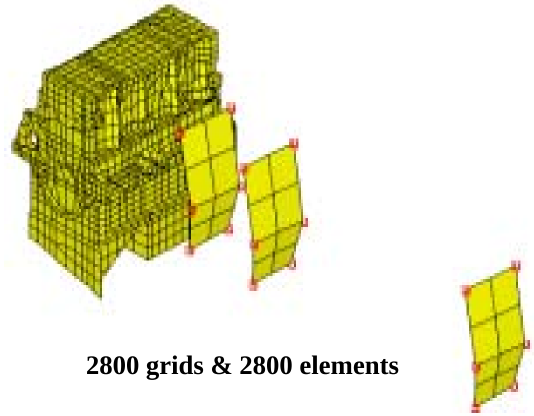


Structural FE Mesh



7400 grids & 6400 elements

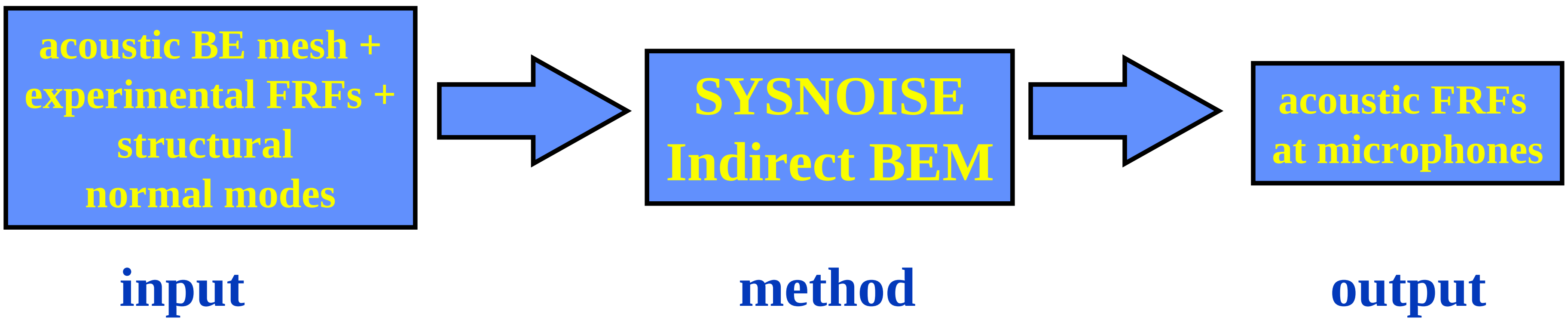
Acoustic BE Mesh



2800 grids & 2800 elements

Engine Noise : Test-Analysis Correlation

- **Comparison** between
  - acoustic test
  - BE radiation analysis
- Use of experimental vibration data as input for **SYSNOISE**
- **Modal Expansion**

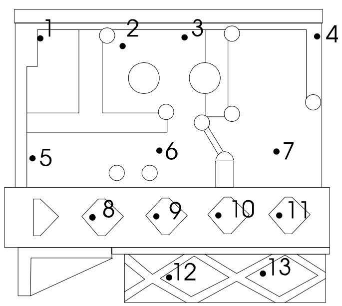


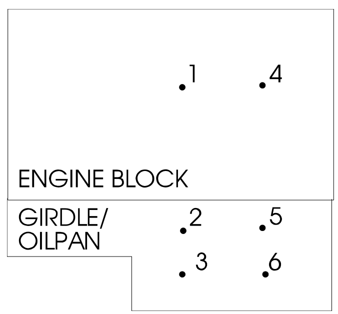
Experimental Test Set-Up

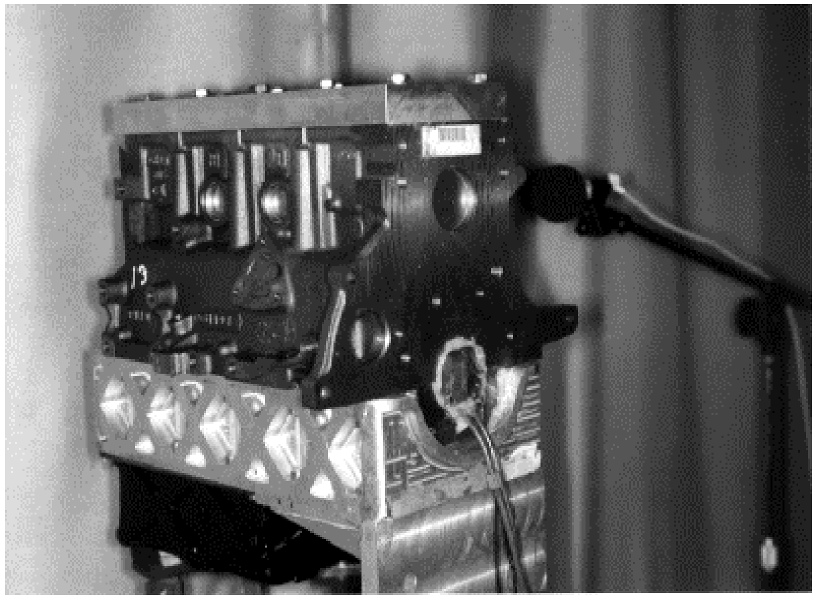
0 Hammer excitation in **bearing 4**

0 **Measurements**

- 4 **Structural**
  - 8 13 points
  - 8 on front face
- 4 **Acoustic** (SPL)
  - 8 distance = 0.1 m
  - 8 averaged on 6 points







Model Courtesy of Ford

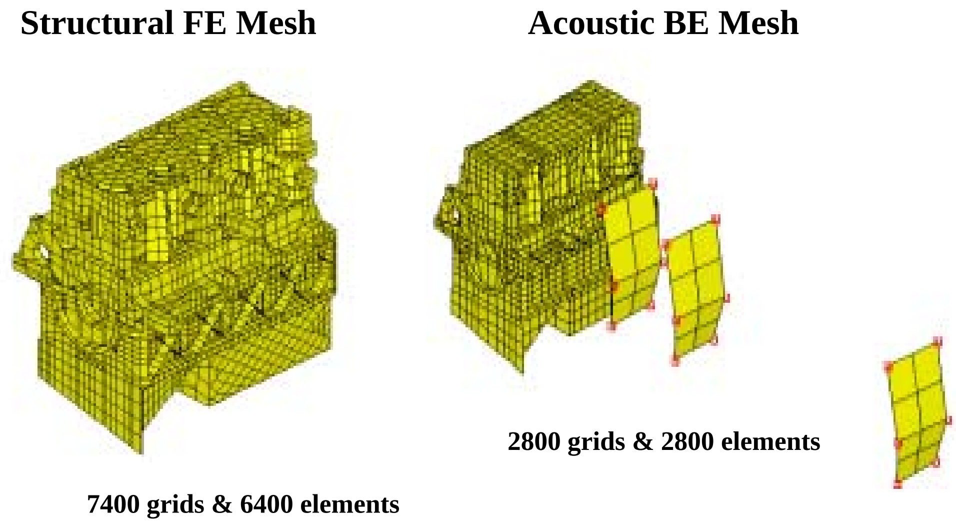
Structural and Acoustic Meshes

0 **Structural FE mesh**

- 4 volume elements
- 4 lumped masses
- 4 beam elements
- 4 interior surfaces

0 **Mesh Coarsening**

- 4 suppress internal parts
- 4 detect and remove the ribs
- 4 increase the size of the elements (6 elements per acoustic wavelength is enough for the radiation analysis)
- 4 end up with the radiating surface only = **BE Mesh**



Modal Expansion

0 **Assumptions**

- 4 **experimental data are reliable and sufficient**
  - 8 accurate damping
  - 8 accurate boundary conditions
  - 8 accurate load
- 4 **mode shapes are correct**
  - 8 correlated with measurements

ombine structural mode shapes to match the actual dynamic response of the structure

0 **For each frequency**

MEASURE-MENT = Σ [**MODE SHAPES** * **PARTIC. FACT.**]

13 34 34 unknown

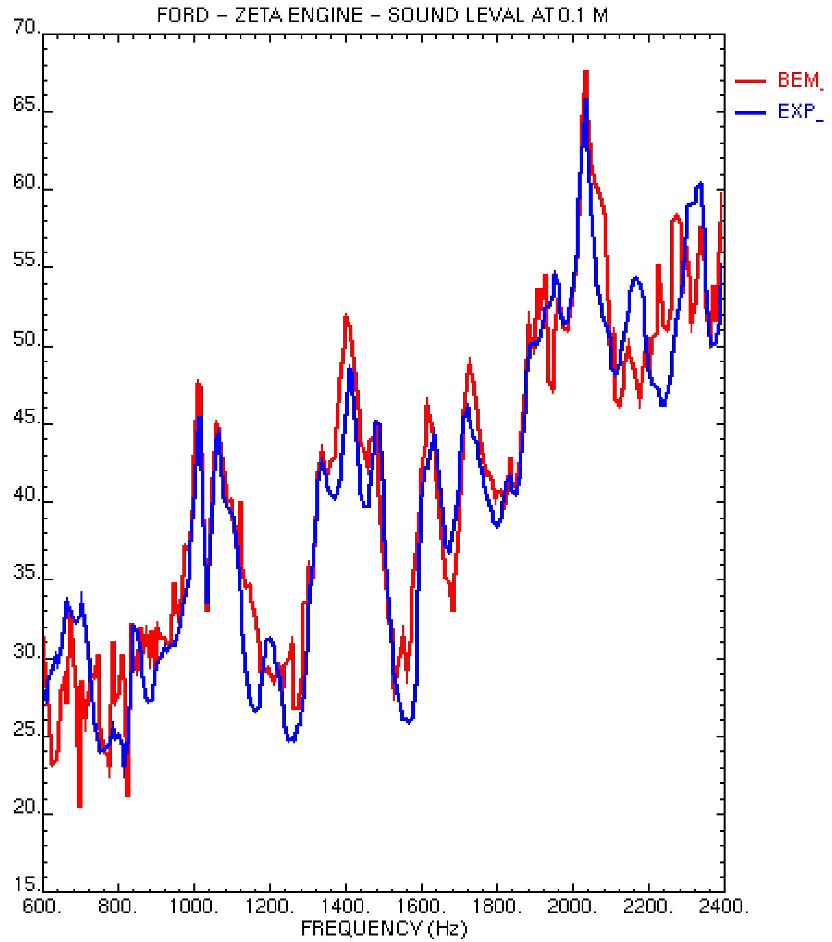
0 **Singular Value Decomposition**

Acoustic Results and Conclusion

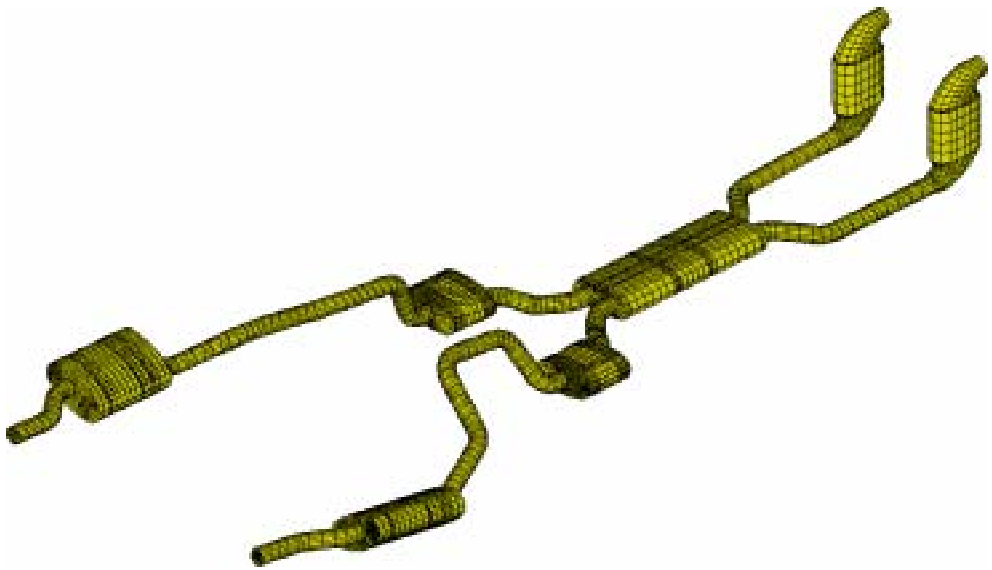
- **Diamonds in, diamonds out !**
- **Comparison**
  (distance = 0.10m)
  - **measured** pressure
  - **computed** pressure

=> **Very Good Correlation**

- **Modal Expansion**
  - validated
- **Acoustic Radiation**
  - accurate if accurate boundary conditions



消音器傳輸損失計算



Double Line Exhaust System

- Many tools for modeling **duct noise** and **shell radiation**
  - **finite elements**
    - surface absorption and perforated pipes
    - inhomogeneous fluid (porous material, temperature gradients,...)
    - flow effects
    - time and frequency domain analysis

  - **boundary elements**
    - surface absorption and perforated pipes
    - uncoupled or coupled (shell noise) analysis

Acoustic Model

0 **Acoustic FE Mesh**

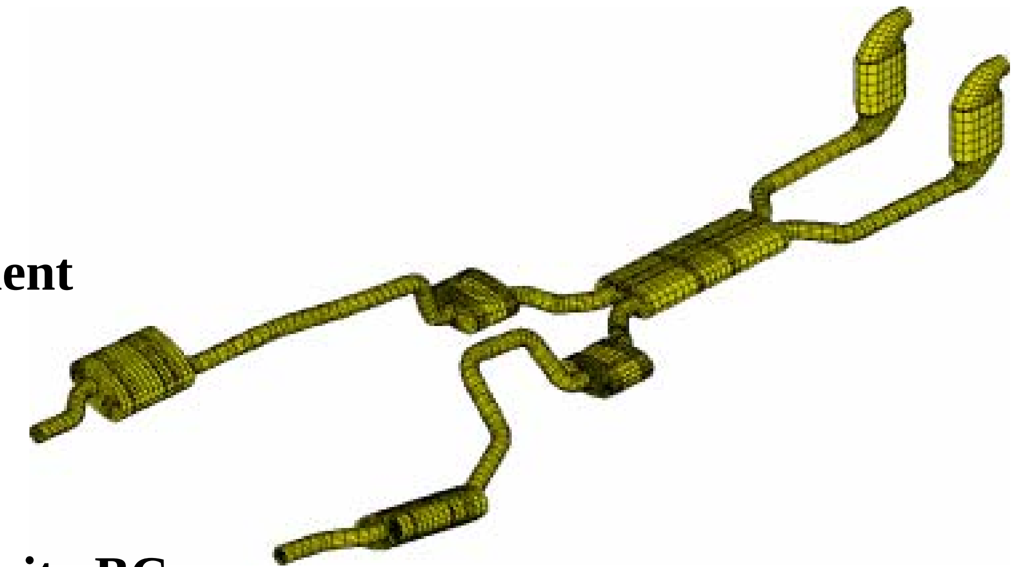
- 4 46966 nodes and 39254 elements

0 **Acoustic Properties**

- 4 Acoustic medium = **air**
- 4 **Perforated** pipes
- 4 Strong temperature **gradient** (500 ^{0}C -> 50 ^{0}C)

0 **Excitation**

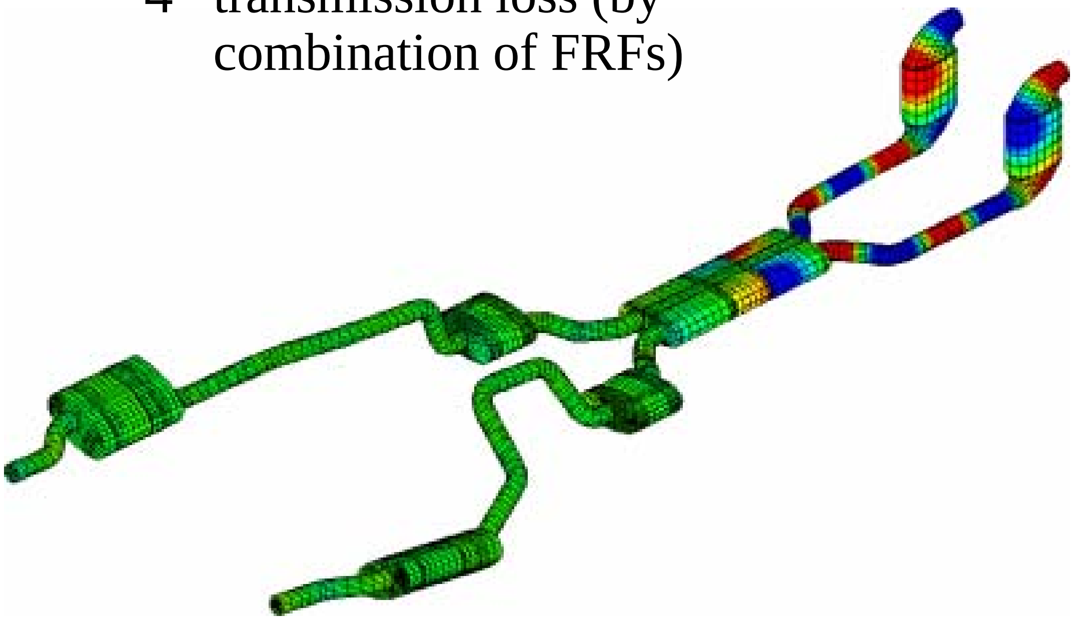
- 4 2 inlet pipes
- 4 **engine pulsations** = **velocity BCs**
- 4 **phase difference** : 180 degrees

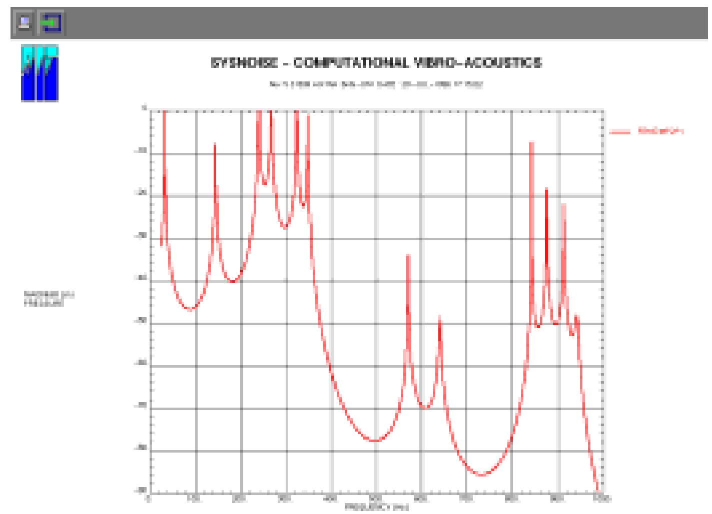


Model Courtesy of Bosal

Acoustic Response Calculation

- **Pipe noise**
  - for one single frequency or on a frequency range
  - transmission loss (by combination of FRFs)





Flow Effects

- **2-step approach**
  - compute flow field
    - in **SYSNOISE** : stationnary, inviscid, irrotational flow
    - in **CFD package** + **import to SYSNOISE**
  - compute acoustic field (convected wave equation)
- **Flow field**
  - flow potential and flow velocity BCs
  - frequency independent
- **Acoustic field**
  - influenced by flow field
  - frequency domain

Transient Analysis

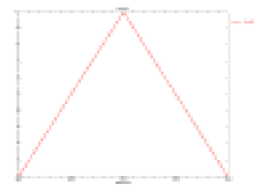
0 **Acoustic FE or BE**

0 Time dependent **acceleration** BCs

0 **Impedance** BCs for :

  8 open outlet end

  8 surface absorption

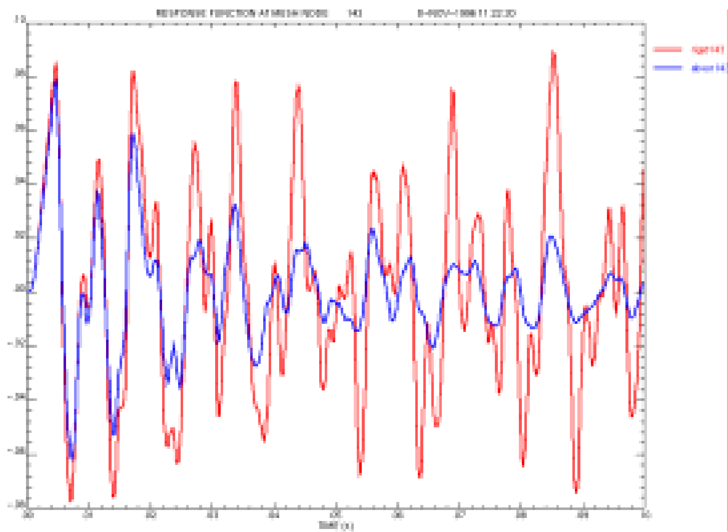


0 **Transient response**

0 **Time Response Functions**

  4 you can listen to it

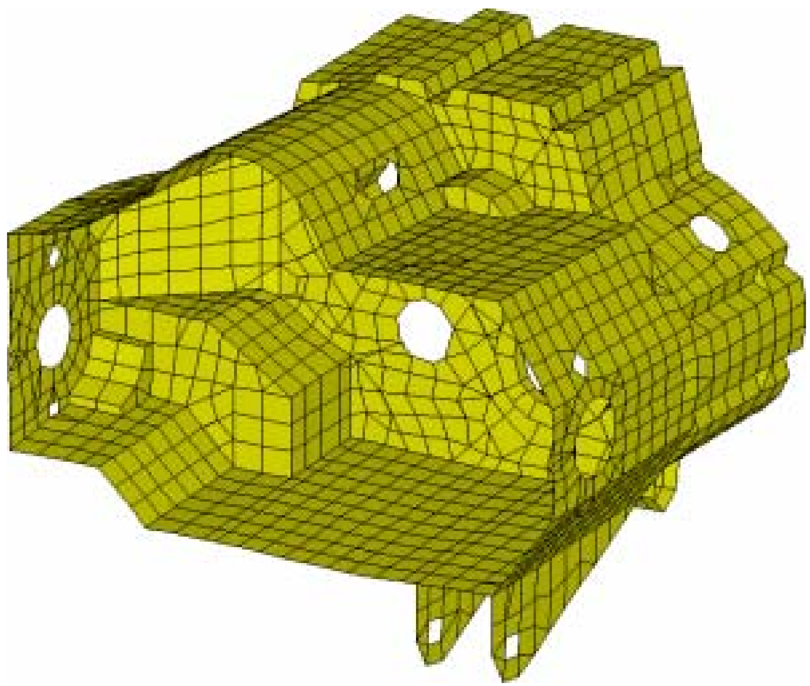
  4 you can apply FFT
  to switch to the
  frequency domain



Conclusion

- **Multitude of tools** for duct acoustics
  - **HVAC** systems
  - **air in-take** systems
  - **exhaust** systems
- Choice of method is **application dependent**
  - flow effects ? temperature effects ?
  - transient or harmonic ? uncoupled or coupled ?
  - homogeneous fluid ? perforated pipes ? surface absorption ?
- **Further post-processing**
  - **audio replay**
  - interface to **Sound Quality** Monitor (SQ-MON of LMS)

齒輪箱噪音



Gearbox Sound Radiation

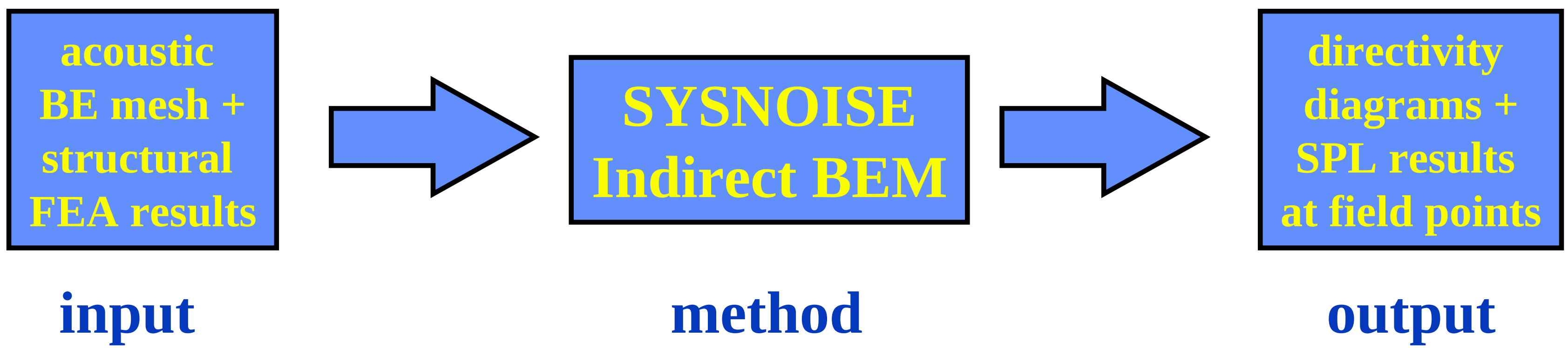
0 Compliance with **Pass-by-Noise Regulation**

0 **Automatic Model Handling**

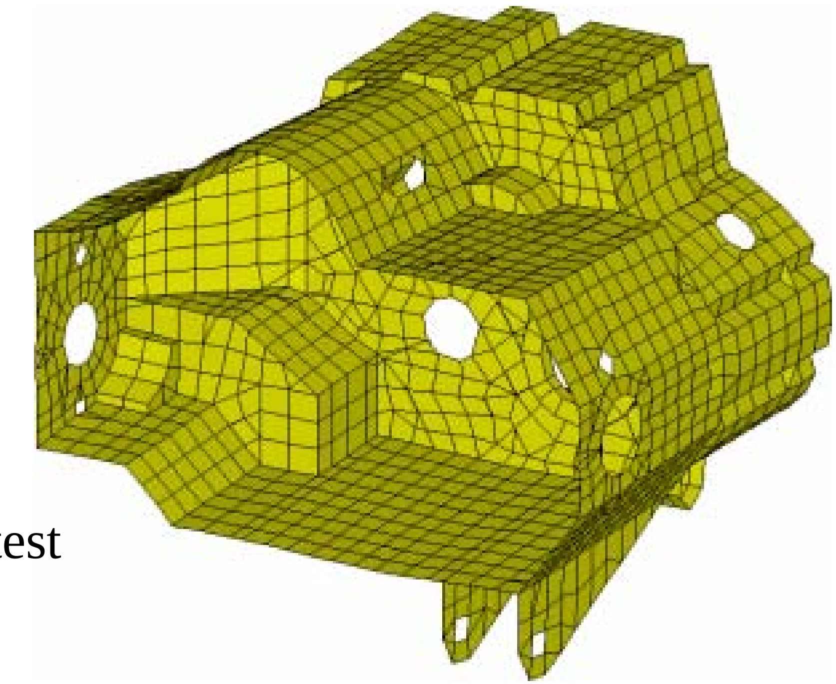
- 4 automatic verification
- 4 automatic correction

0 **Non-Linear** Matrix Frequency **Interpolation**

- 4 faster solution
- 4 same accuracy



Pass-By-Noise Test (Europe : ISO 362)

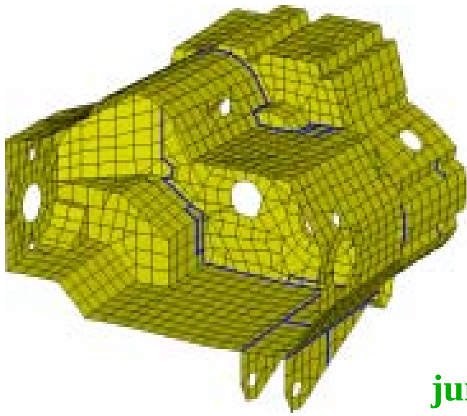


- **Running Vehicle**
  - initial speed = 50km/h
  - 2 tests : second and third gear
  - accelerate at full throttle
- **Measurement Points**
  - immobile, standardized position
  - SPL < 77 dBA during the whole test
- **Many Contributions**
  - road/wheel noise
  - engine noise
  - aerodynamic noise
  - noise of components : exhaust, **gearbox**, ...

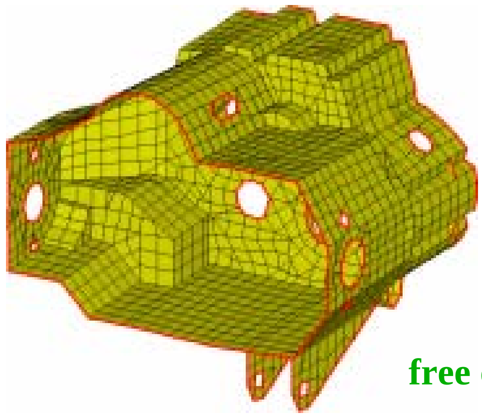
Model Courtesy of BMW Munchen

Acoustic Model

- **Acoustic BE Mesh**
  - 1.827 nodes, 1.899 elements
- **Automatic Mesh Handling**
  - normals correction
  - junctions (523)
    - detection of junctions
    - junction constraints
  - free edges
- **Excitation**
  - vibration of the gearbox shell
  - gear noise
- **Frequency :** 500 to 1500 (Step 5 Hz) = 201 Steps



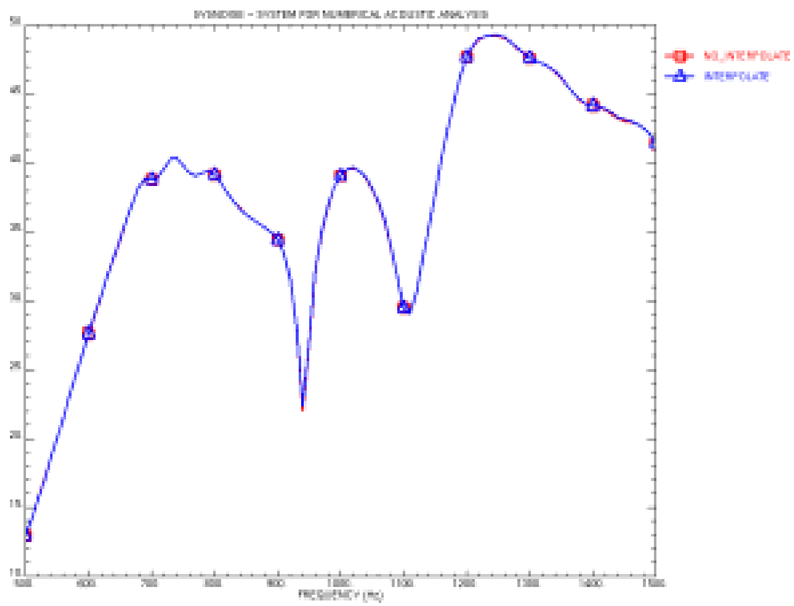
junctions



free edges

Acoustic Response (CRAY C90)

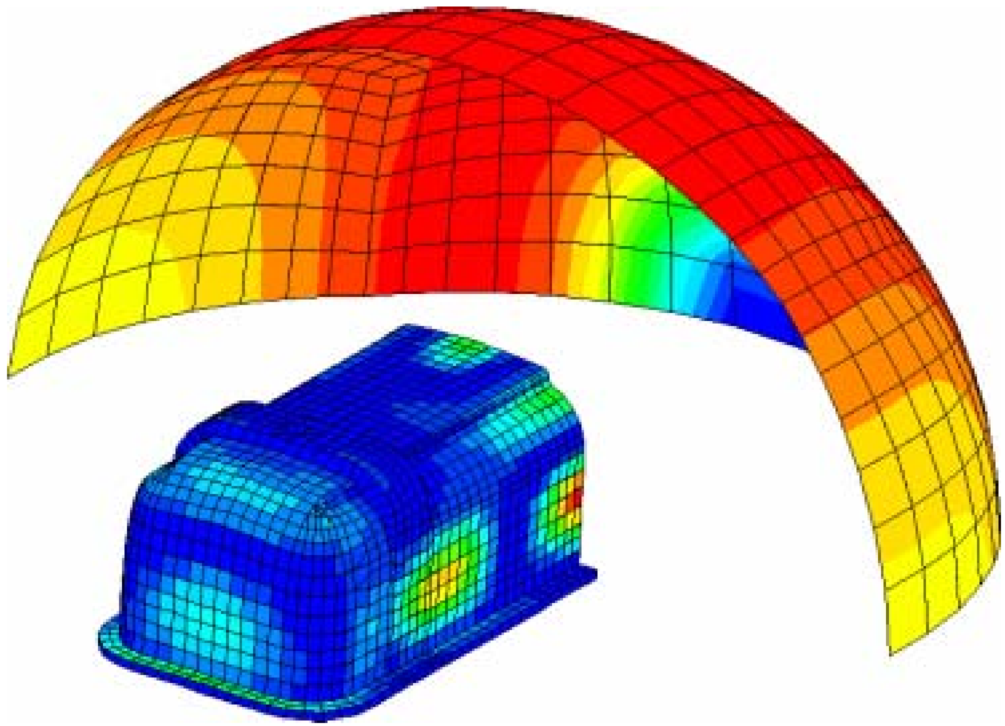
- **Frequency Interpolation Technique**
  - **master** frequencies : **system assembly + solution**
  - **slave** frequencies : **system interpolation + solution**
- CPU time **without** Interpolation (frequency step = 5 Hz)
  - **assembly** : 105 * 201 = 21105 sec
  - **solution** : 20*201 = 4020 sec
  - **total : 25125 sec**
- CPU Time **with** Interpolation (frequency step = 50 Hz, interpolation every 5 Hz)
  - **assembly** : 105 * 21 = 2205 sec
  - **solution** : 20 * 201 = 4020 sec
  - **total : 6225 sec -> 4 times faster !!!**



Conclusion

- **Fully Automatic Mesh Handling**
  - mesh verification
  - mesh correction
- **Matrix Frequency Interpolation**
  - **non linear**
  - important **time saving**
  - quality of results kept
- **Pass-by-Noise Requirements** are Satisfied

引擎閥蓋噪音



Valve Cover Radiation

0 Sound Radiated from **Truck Engine Valve Cover**

0 **Automatic Mesh Treatment** in **SYSNOISE**

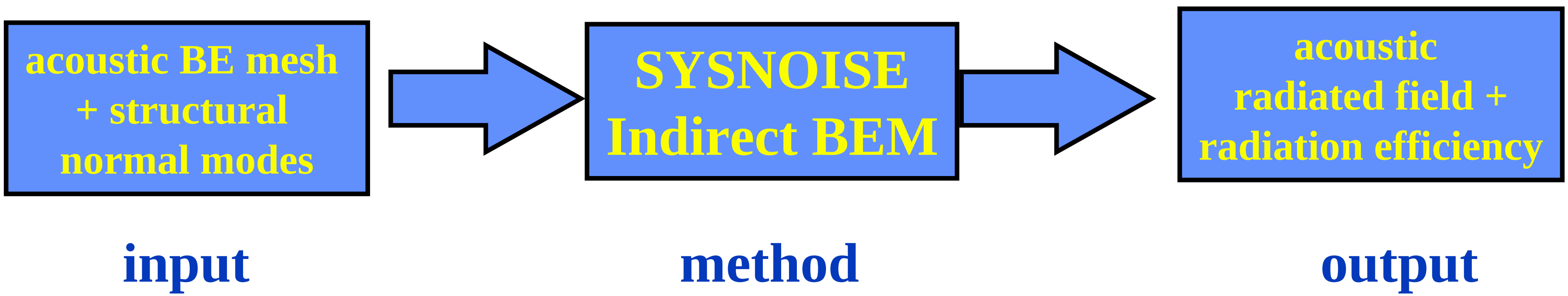
  4 normals correction and rib removal

0 Symmetry planes and Reflective Halfspaces

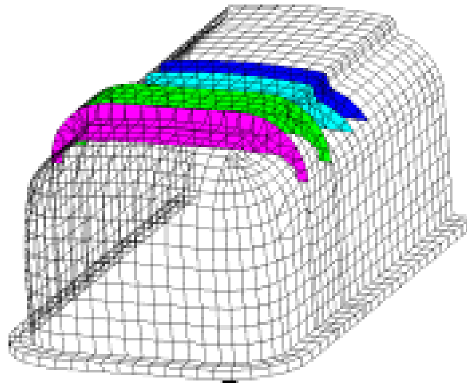
0 **Analysis**

  4 radiation from structural normal mode

  4 comparison of radiation efficiencies

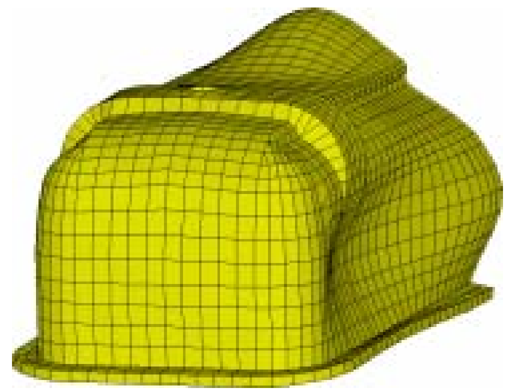


Structural Model



Model Courtesy of Renault VI

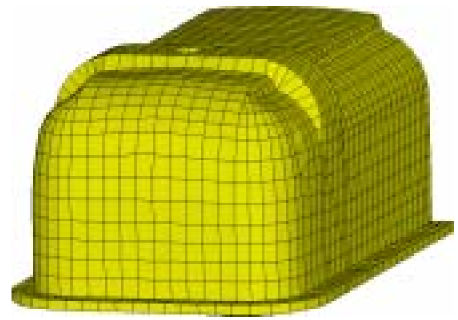
- **Structural FE Mesh**
  - 1771 nodes
  - 1758 elements
  - symmetric
  - contains ribs
- **Structural Deflection**
  - mode shape 6 - 843.3 Hz

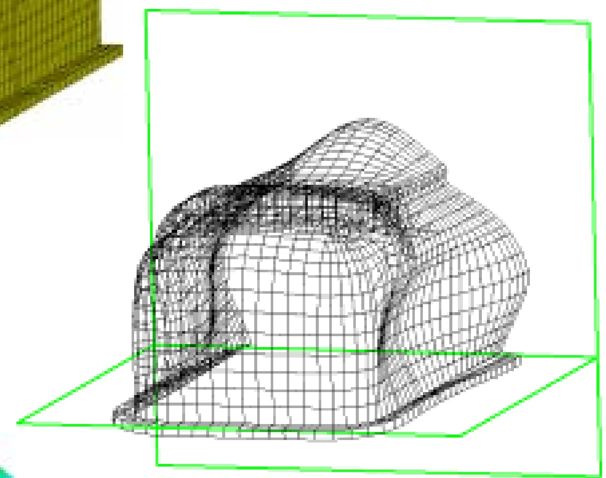


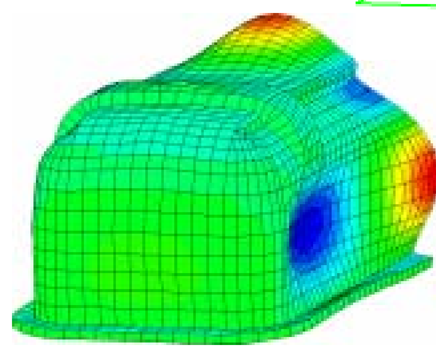
- **Rib Handling**
  - interior ribs
  - no direct contribution to acoustic field
  - mesh coarsener of SYSNOISE
    - automatic rib detection and removal

Acoustic Model

- 0 Option BEM Indirect
- 0 **Automatic Mesh Handling**
  - 4 normals
  - 4 junctions
  - 4 free edges
- 0 **Model Handling**
  - 4 symmetry plane
  - 4 rigid halfspace plane
- 0 **Automatic BCs Generation**
  - 4 **incompatible** meshes
  - 4 projection on normal
  - 4 conversion to velocities



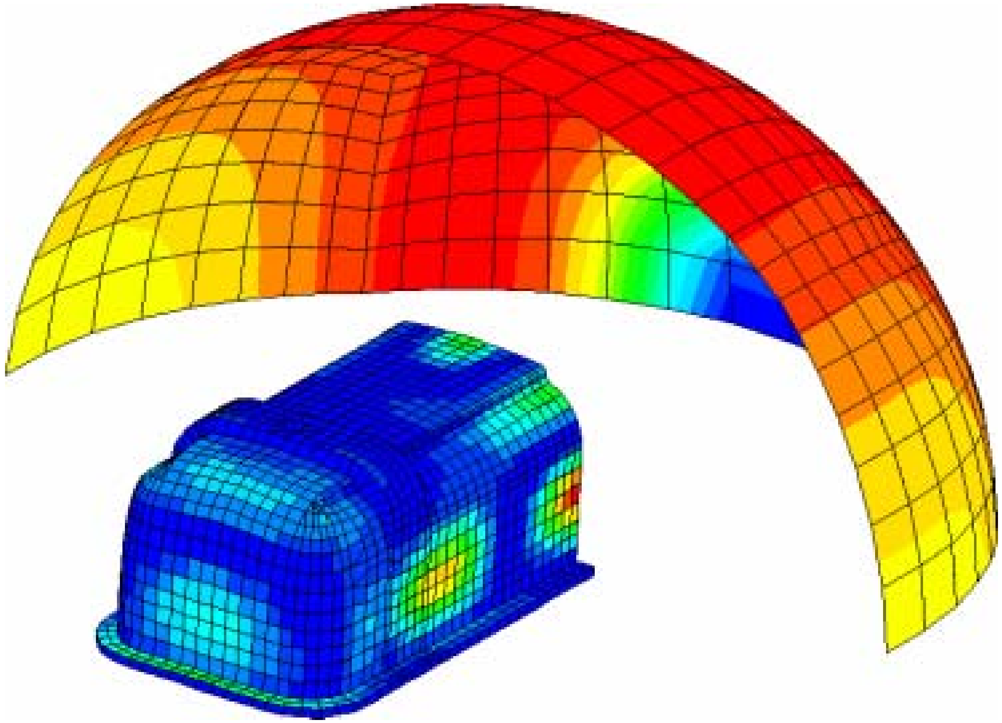




Acoustic Radiated Field

0 **Results**

- 4 mesh
  - 8 potentials
  - 8 input and radiated power
  - 8 **power densities**
  - 8 radiation efficiency
- 4 field point mesh
  - 8 **pressure**
  - 8 velocity
  - 8 intensity
  - 8 radiated power



Conclusion

0 **Starting from a Structural FE Model**

- 4 structural FE mesh
- 4 structural modal basis

0 **Automatic Handling of the Mesh**

- 4 very robust algorithms
- 4 very fast update of the model

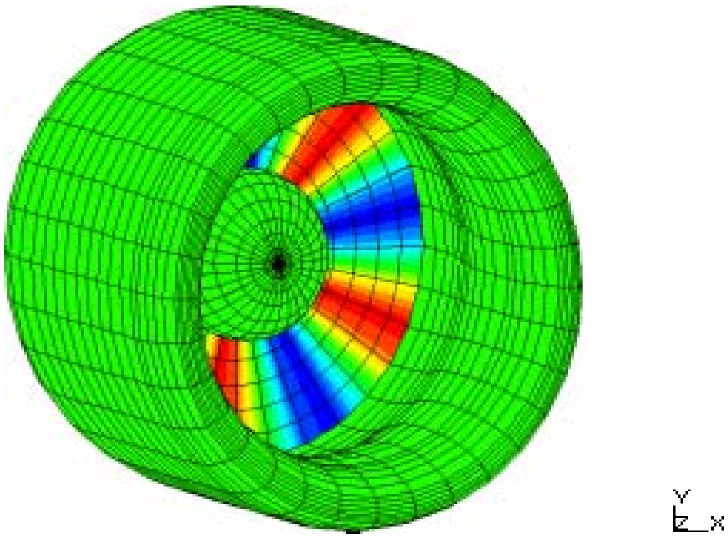
0 **Easy Transfer of Structural Deflection**

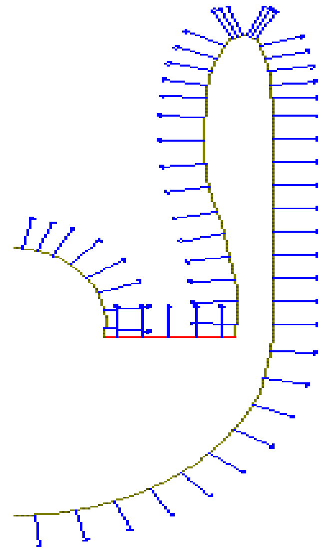
0 **Acoustic Radiation Analysis**

0 Vibro-Acoustic Results

- 4 detailled results
- 4 easy representation

飛機渦輪葉片噪音





Aircraft Fan Noise

0 **Acoustic Radiation using Indirect BEM**

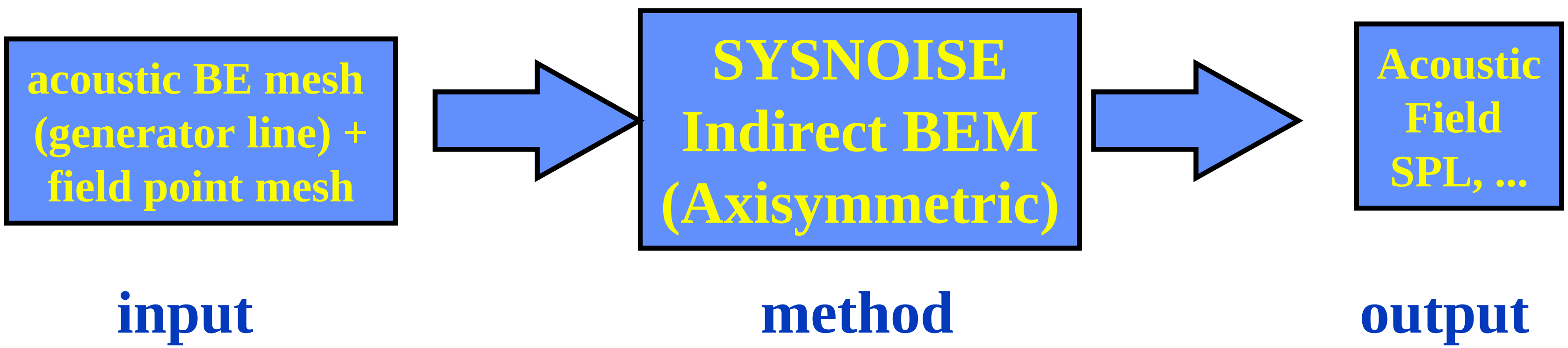
0 **Axisymmetric Model**

4 axisymmetric geometry

4 non-axisymmetric excitation

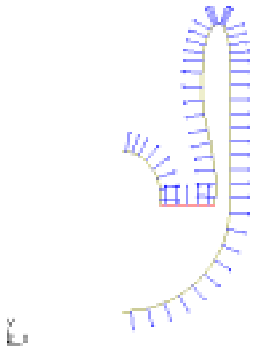
4 Fourier decomposition

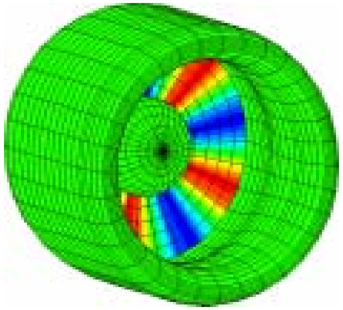
0 **Easy Post-processing**



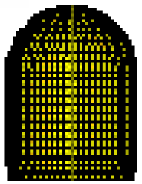
Acoustic BE Model

- **Acoustic BE Mesh (Axisymmetric)**
  - **only** 60 nodes, 59 LINE2 elements
  - automatic verification of normals
- **Automatic Axisymmetric Mesh Expansion**
  - 3D mesh
  - refinement = 5
- **Boundary Conditions**
  - order 5 => **Fourier decomposition**
  - **possible BCs in SYSNOISE**
    - **velocity**, pressure
    - impedance/admittance
    - continuous or **discontinuous**
    - **combination**



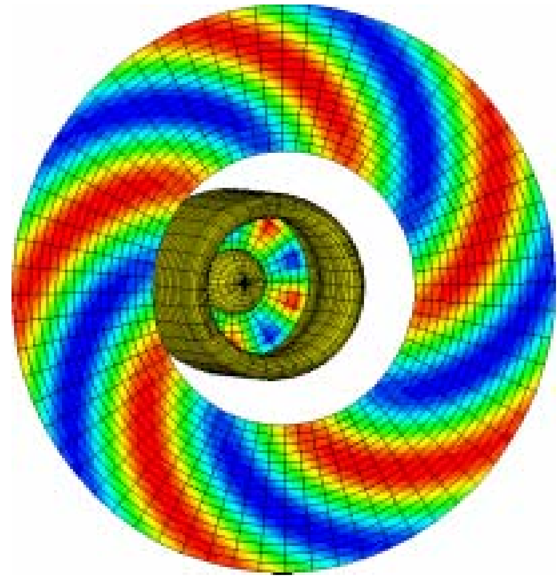


harmonic order 5

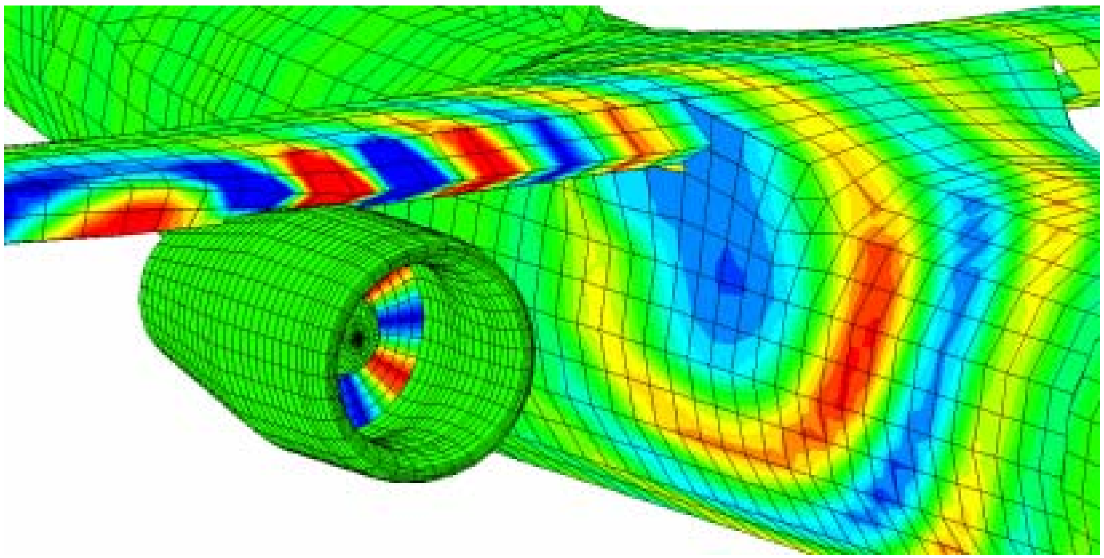


Acoustic Field Evaluation

- **Very Fast Calculation** (like a 2D Model)
- **Acoustic Field**
  - pure radiation
  - scattering on fuselage



Pressure field - 500Hz



Scattered field - 500Hz

Conclusion

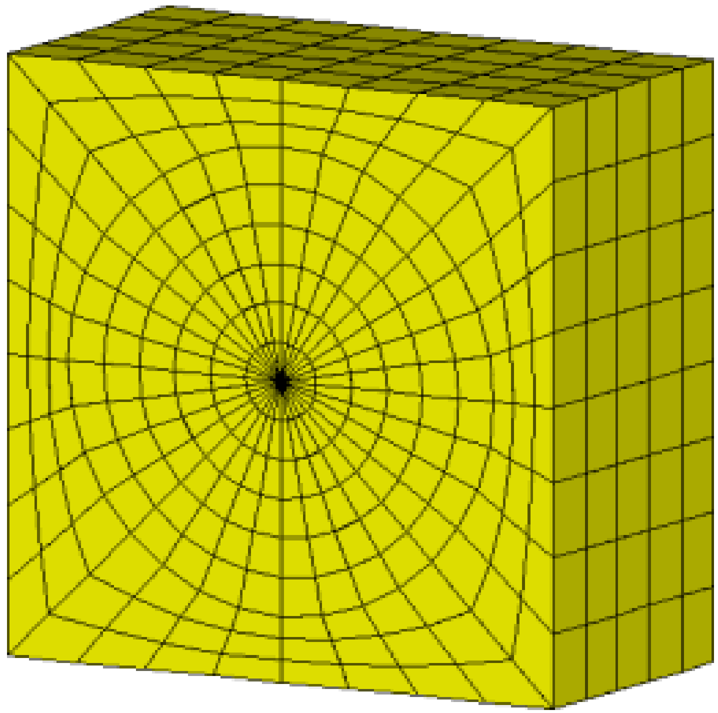
0 **Unique Features** for Solving Axisymmetric Problems like Aircraft Fan Noise Problems

- 4 axisymmetric geometry
- 4 automatic mesh expansion
- 4 boundary condition
  - 8 general 3D
  - 8 **harmonic** (order to be specified)

0 **Very Short CPU Time**

0 Full 3D Post-processing Possible

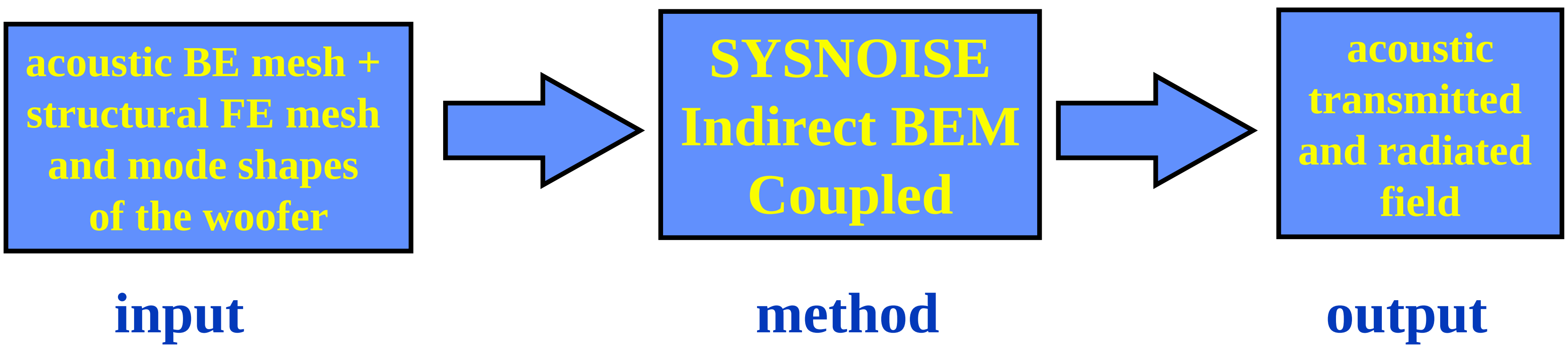
喇叭流場結構互動行為分析



Loudspeaker Radiation Analysis

0 **Coupled BEM Indirect/FEM Structure**

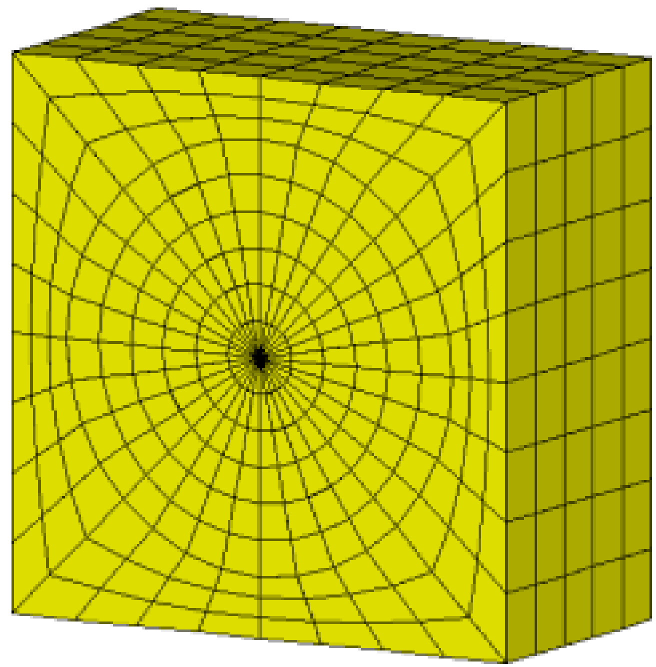
- 4 fluid inside and outside of the loudspeaker
- 4 rigid loudspeaker box
- 4 very thin flexible woofer
- 4 added mass effect
  - 8 of air on woofer
  - 8 responsible for sound characteristic of the woofer



Acoustic Model

0 **Acoustic BE Mesh**

- 4 498 nodes, 512 elements
- 4 normals
  - 8 must point consistently
  - 8 automatic handling
- 4 fluid = air
  - 8 density = 1.2 kg/m^3
  - 8 sound speed = 340 m/s
- 4 loudspeaker box
  - 8 rigid
- 4 woofer
  - 8 flexible (see structural model)
- 4 field point mesh



Structural FE Model

0 **Woofer FE Mesh**

  4 shell elements

0 **Boundary Conditions**

  4 clamped on the edges

  4 excitation

    8 point force

0 **Woofer FE Modal Basis**

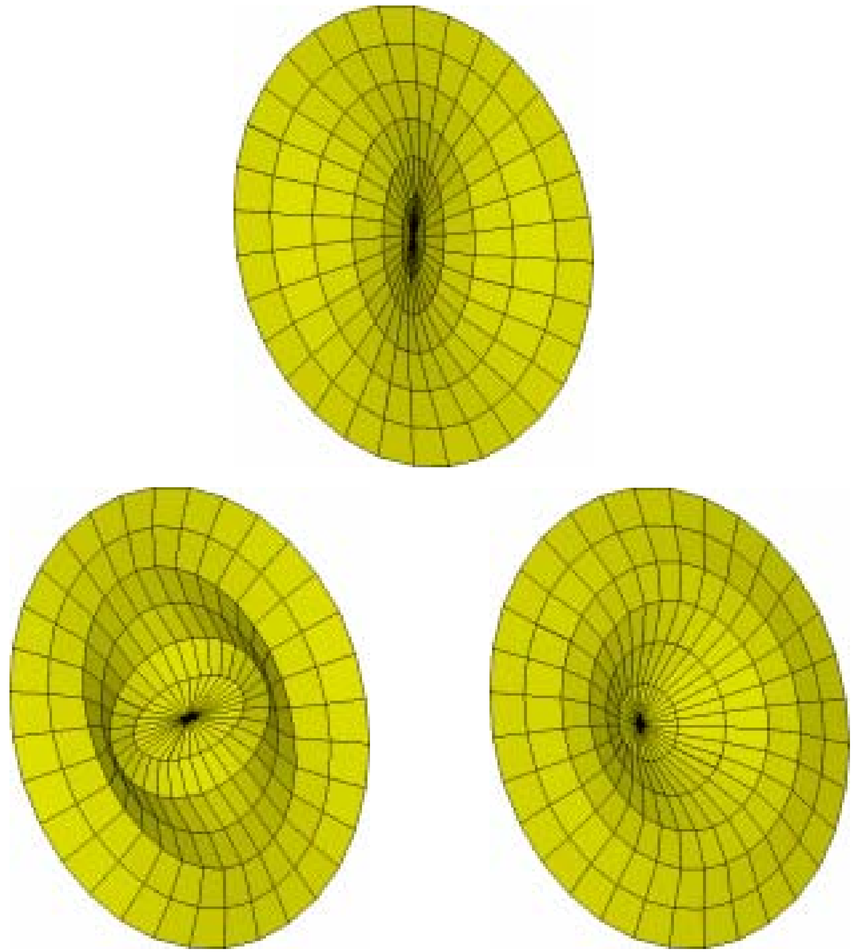
  4 10 structural modes

  4 up to 1347 Hz

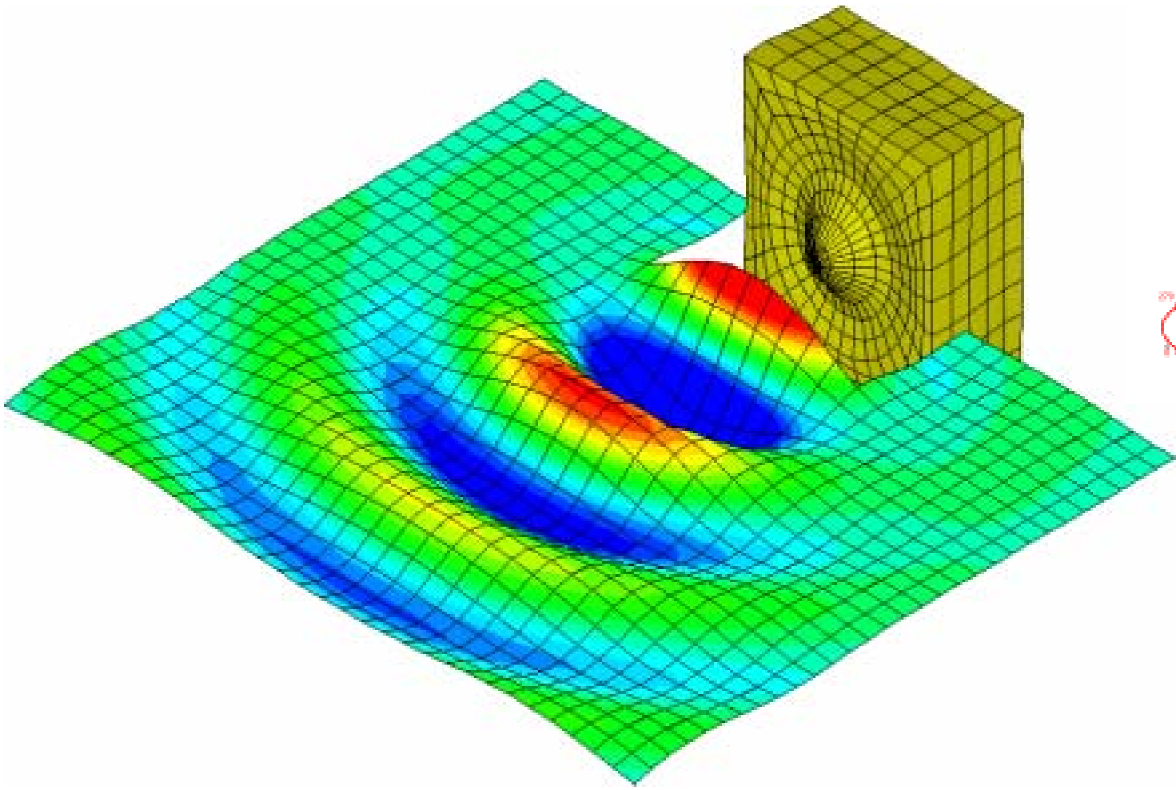
0 **Coupling Models**

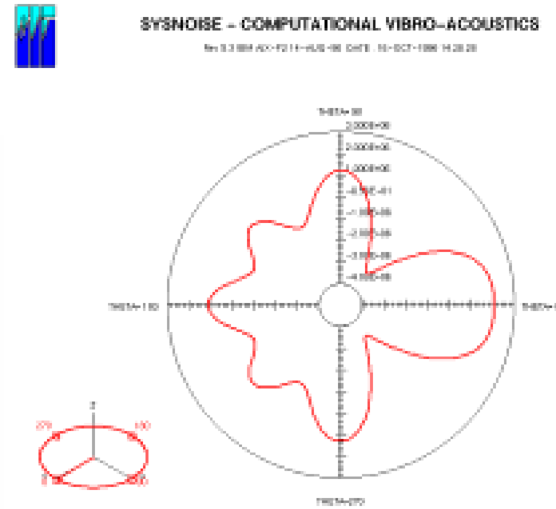
  4 fluid-structure link

  4 on the woofer only



Radiated Pressure Field - 500 Hz

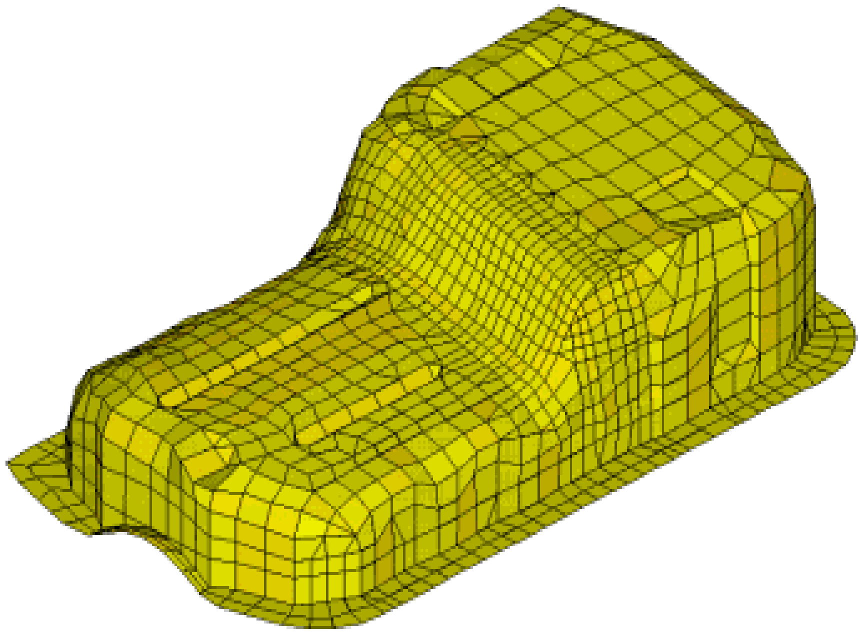




Conclusion

- 0 **Loudspeaker Model**
  - 4 rigid loudspeaker box
  - 4 very flexible and thin woofer (membrane)
  - 4 fluid on both sides of the box faces
- 0 **Coupled BEM Indirect/FEM Structure**
  - 4 fluid-structure link
  - 4 sound transmission (through the woofer)
  - 4 exterior acoustic field
    - 8 pressure field
    - 8 directivity pattern

油底殼設計靈敏度分析



Oilpan Global Sensitivity Analysis

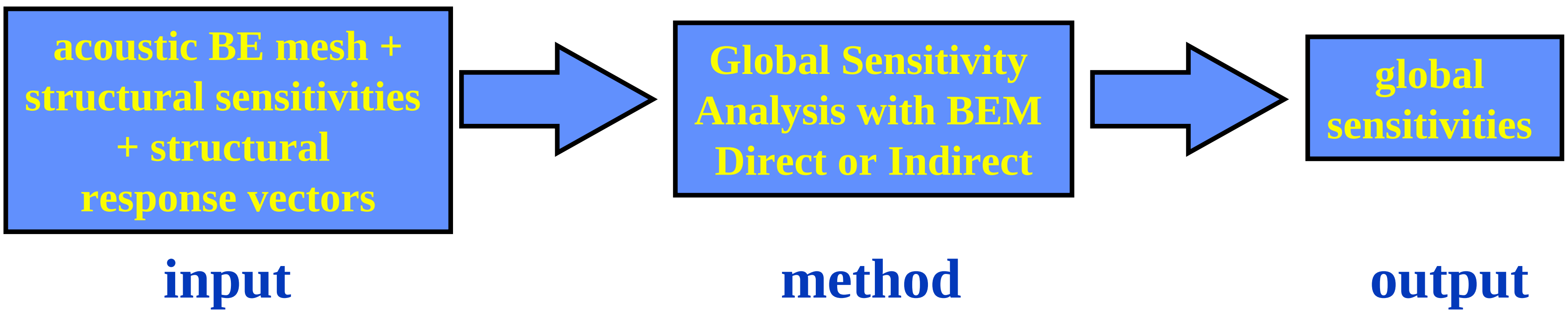
0 Traditional acoustic BE analysis **only gives results for**

- 4 radiated sound pressure
- 4 radiated sound power

0 but **no information** on

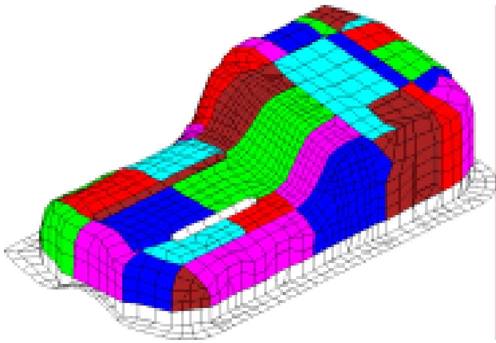
- 4 where to make design modifications ?
- 4 which changes to make ?

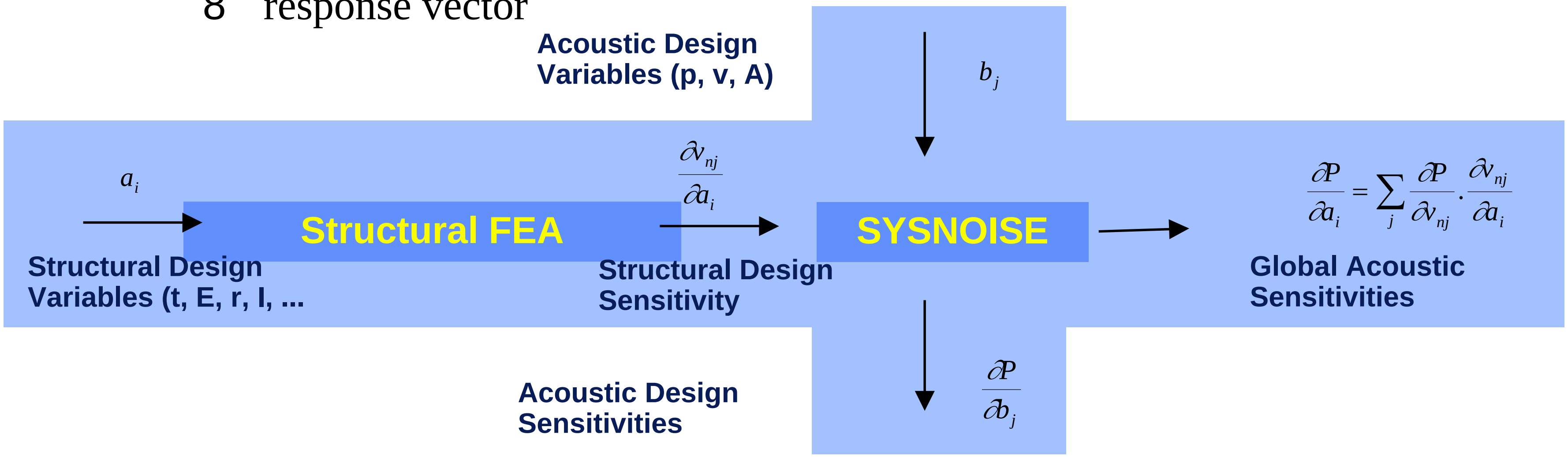
0 Solution : **Global Sensitivity Analysis**



Structural FE Model

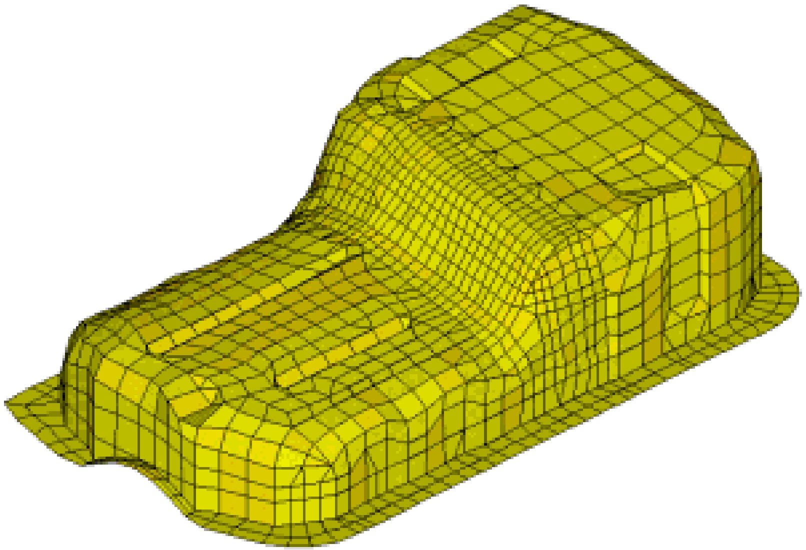
- Define Thickness **Design Variables**
- Compute **Structural Sensitivities**
- **Transfer to SYSNOISE**
  - for every frequency
    - structural sensitivity vectors (1 per design variable)
    - response vector





Acoustic BE Model

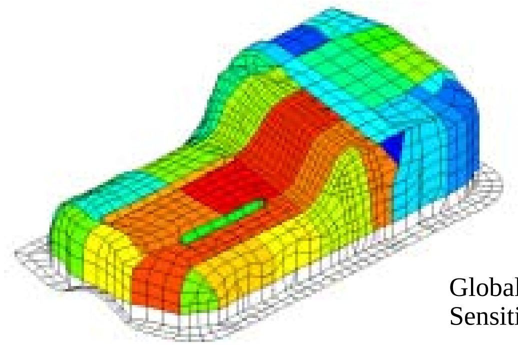
- **Acoustic BE Mesh**
  - radiating surface
  - 1620 nodes, 1550 elements
- **Problem**
  - radiated power too high
  - near 1.000 Hz
- **Solution Steps**
  - compute the **sensitivity** of radiated power with respect to panel thickness design variables
  - see which part is the most **sensitive**
  - **change** the thickness (stiffness) of this part
  - **verify** the improved model



Model Courtesy of Honda

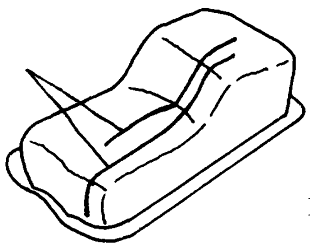
Global Sensitivity Results

- **Show clearly what to do**
  - where the sensitivity is high, the effect on radiated power is more important



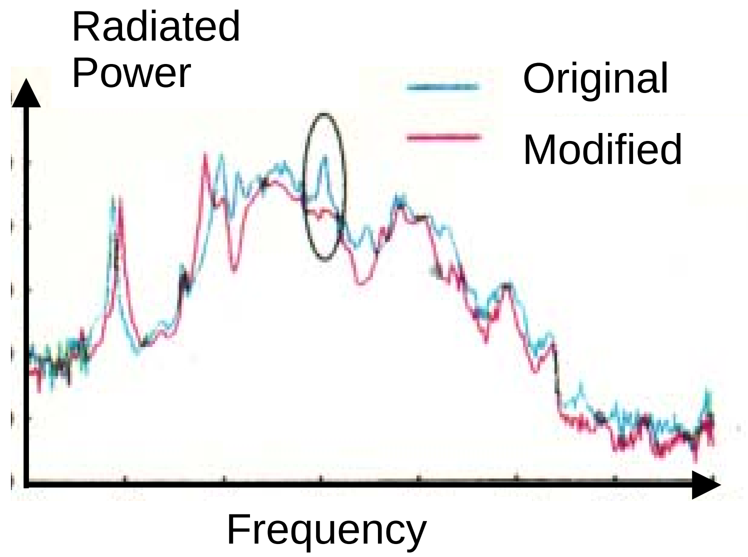
Global Sensitivity

- **Solution**
  - difficult to increase thickness
  - => add stiffeners



Modified Structure

- **Radiated Power** FRF
  - shows improvement
  - about **4.6 dB**



Conclusion

0 **No more trial-and-error** iterations

0 **SYSNOISE clearly indicates**

  4 **where** changes have to be made on the structure

  4 what is the **impact** of these changes on the acoustic field

0 Significant **cost savings**

0 **Reduced time-to-market**

0 **Further extensions**

  4 sensitivities on a frequency range

  4 link to **optimization** techniques : **LMS Optimus**