Acoustic Simulation with Actran

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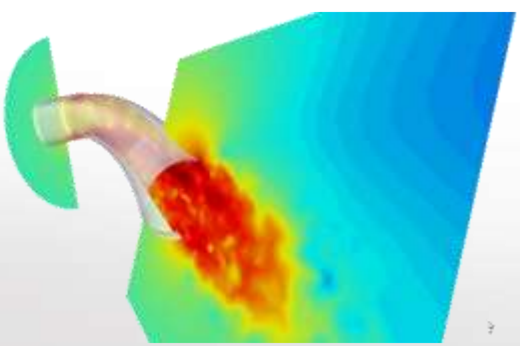
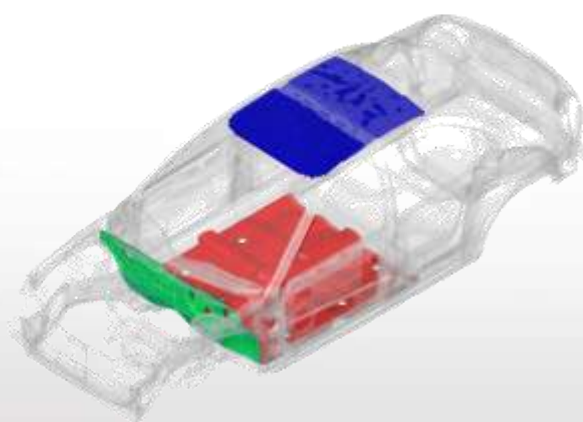
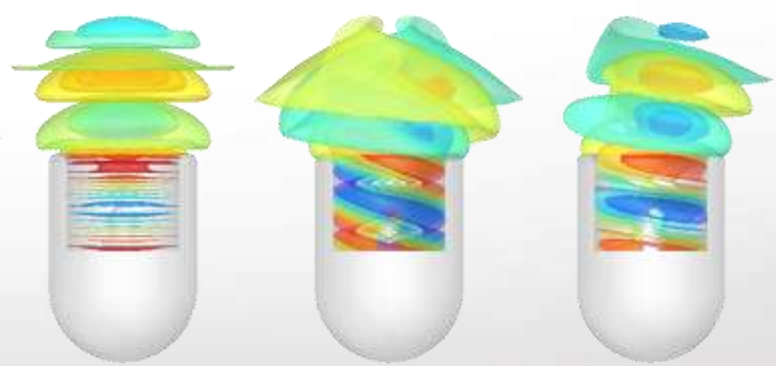
26 November 2012

Agenda

- A quick introduction to Field Technologies (FFT), an MSC Software Company
- Introduction to Acoustics
- Introduction to Numerical Acoustics
- Acoustic, vibro-acoustic and aero-acoustic simulations with Actran
- Some case studies
- Conclusions
- Questions are more than welcome !

Free Field Technologies

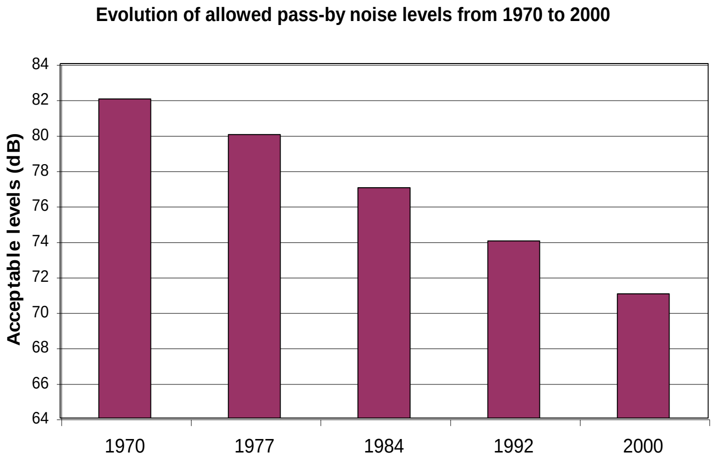
- **Free Field Technologies (FFT) is the technical leader in acoustic, vibro-acoustic and aero-acoustic CAE**
- **The company has three main activities**
  - Development of the Actran software suite
  - Provision of related services: training, consulting, technology transfer, methodology development, installation and performance tuning, custom developments, CAE process automation
  - Research in acoustic CAE and related fields
- **Free Field Technologies operates from its headquarters in Mont-Saint-Guibert (near Brussels), Belgium, and from its offices in Toulouse, France, Tokyo, Japan, and Troy, MI, USA.**
- **Actran is used by over 300 industrial customers worldwide.**
- **FFT joined MSC Software Corporation in September 2011 and became a wholly owned subsidiary of MSC Software.**

Introduction to Acoustics

Some basic concepts to understand what we are talking about

Why acoustics ?

- **Noise is becoming a dominant problematic for different reasons**
- **Stringent norms**
  - The norms defined by States are more and more restrictive
  - It sometimes becomes the dimensioning factor: Airbus A380
- **Comfort**
  - Acoustic comfort (car or aircraft cabin for instance) is a marketing argument today
- **Damages**
  - In the conception of spatial structures, a high level of noise can lead to damages until the break-down of the structure

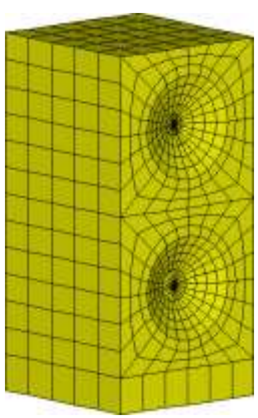


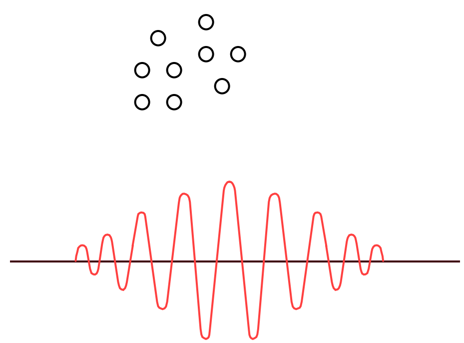
Acoustics ?

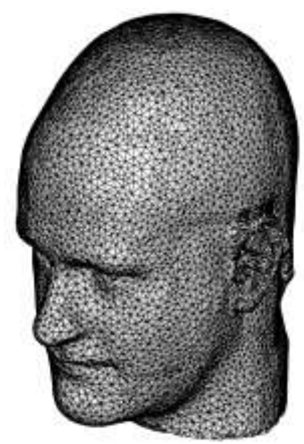
- **A sound is a *small* and *rapid* fluctuation of pressure around a mean pressure value.**
- **Noise and sound**
- **Pressure waves**
  - in air
  - in water
  - in any fluid
  - in any solid
- **Production, propagation and effect on propagation media, reception**

$$p_{atm} = \frac{1}{T}\int_0^T p_{tot}(t)\cdot dt$$

$$p_{ac}(t) = p_{tot}(t) - p_{atm}$$

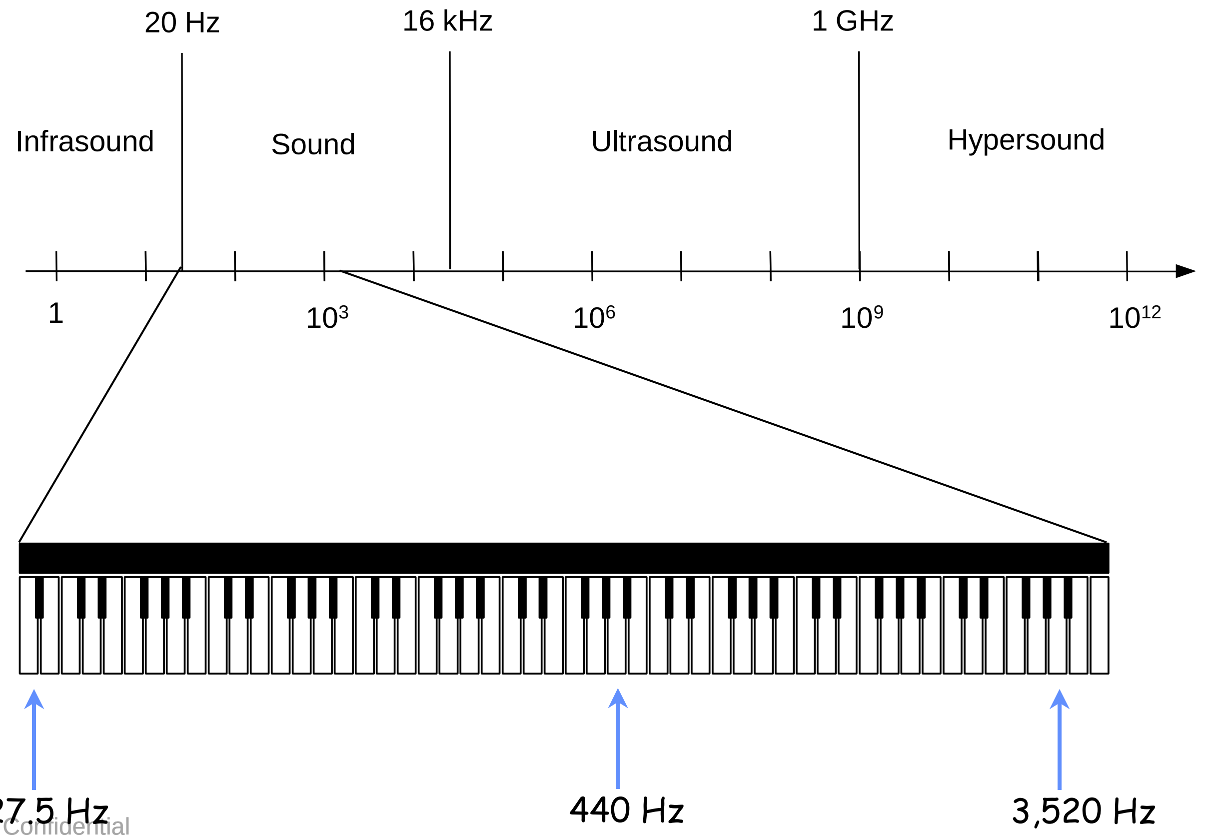




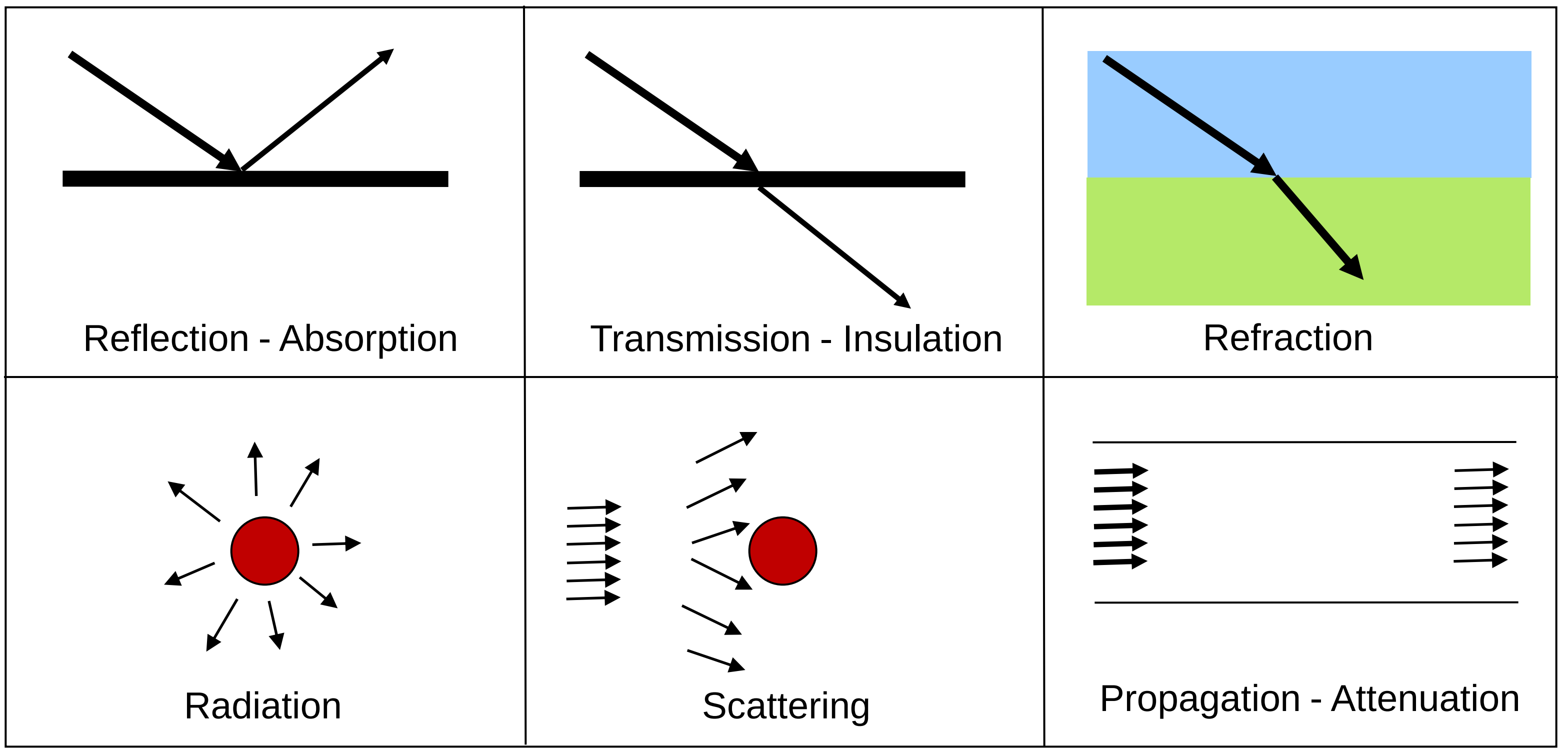


Spectral Extent of Sound Waves

- **Acoustic analysis are generally done in the frequency domain**
  - Structure behaves differently according to the frequency ranges
  - Measurement are done in the time domain
  - Extensive use of the Fourier transform



Some Terminology



Linear vs. Non-Linear Acoustics

- **The immense majority of acoustic phenomena are linear:**
  - proportionality between effect and cause
  - superposition principle
- **Non-linear phenomena appear when:**
  - sound level are very high (jet engines, power ultrasound) → 10% of an atmosphere ~ 150dB
  - source amplitude depends on induced acoustic field (burner noise)
  - mechanical properties of the acoustic medium vary with generated sound field (acoustic cavitation)
- **It is in the field of ultrasound that most non-linear acoustic phenomena are encountered:**
  - sonochemistry / sonoluminescence
  - lithotripsy
  - acoustic cleaning

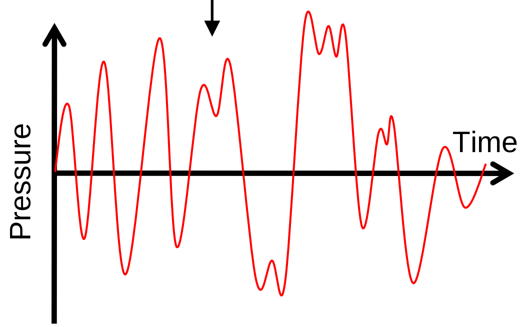
Wave Equation

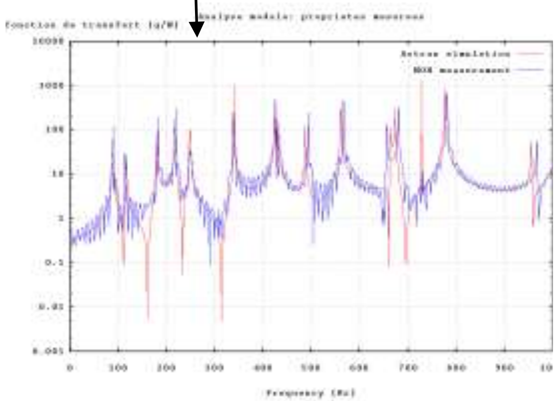
$$P(\omega) = \int_{-\infty}^{\infty} p(t) e^{-i\omega t} dt$$

$$\frac{1}{c^2}\frac{\partial^2 p}{\partial t^2} - \Delta p = 0$$

$$\Delta P + k^2 P = 0$$

$$p(t) = \int_{-\infty}^{\infty} P(\omega) e^{i\omega t} df$$



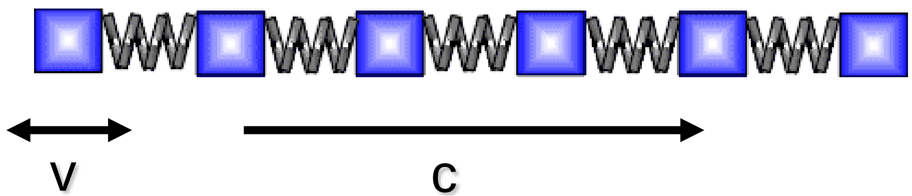


- **Time domain**
  - Data recorded over time p(t)
  - Transient results
    - Structural
    - CFD
    - Acoustics
  - Experimental Data

- **Frequency domain**
  - Data recorded over frequency p(ω)
  - Plus phase angle φ: p(ω,φ)
  - Harmonic or modal results
    - Structural
    - Acoustics

Speed of Sound

- The speed of sound c is the propagation speed of a disturbance in an elastic medium.
- Particles are <u>not</u> transported with the wave
- Particles oscillate for only an infinitesimal distance This is quantified by the particle velocity v.



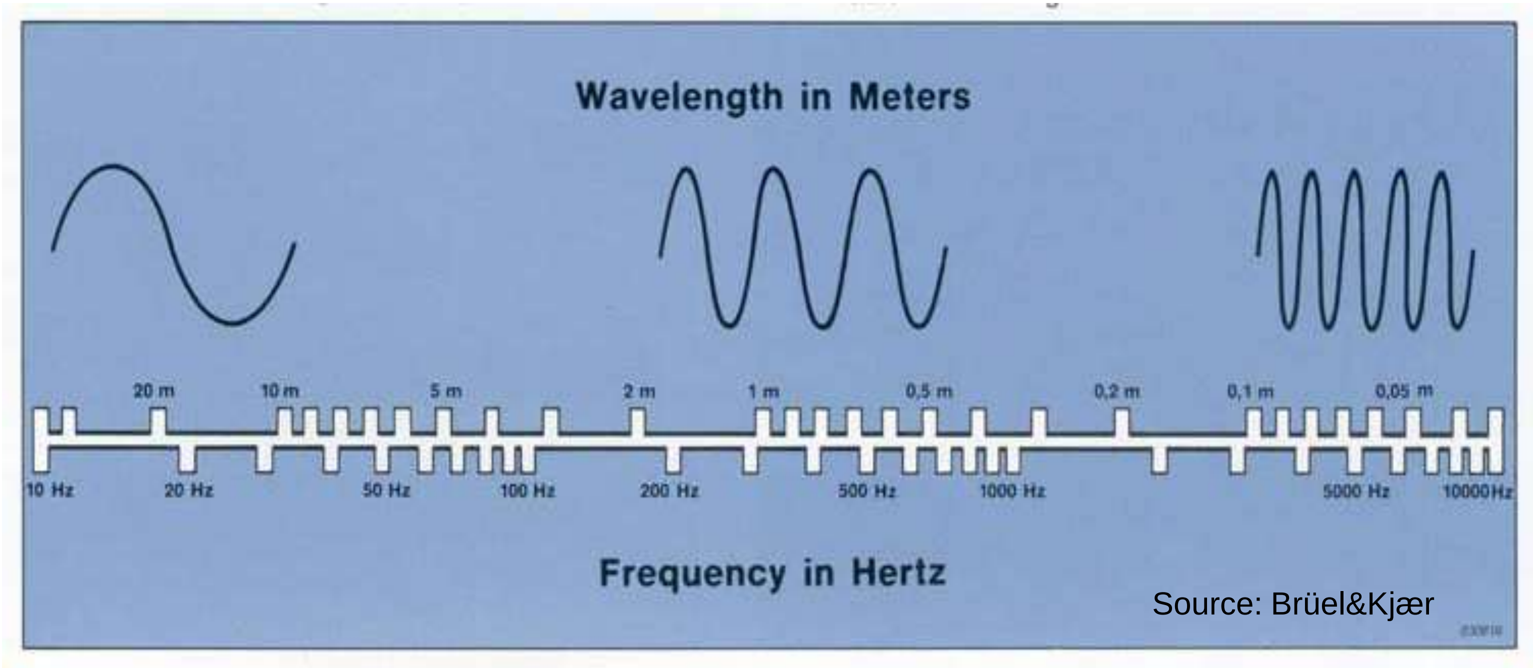
- All other quantities like intensity, radiated power can be computed if the sound pressure p and particle velocity v are known.
- Don’t mix up c and v!

$$c_{fluid} = \sqrt{\frac{K}{\rho}}; c_{idealgas} = \sqrt{\gamma \frac{R}{M} T}$$

Speed of sound – Wavelength – Frequency

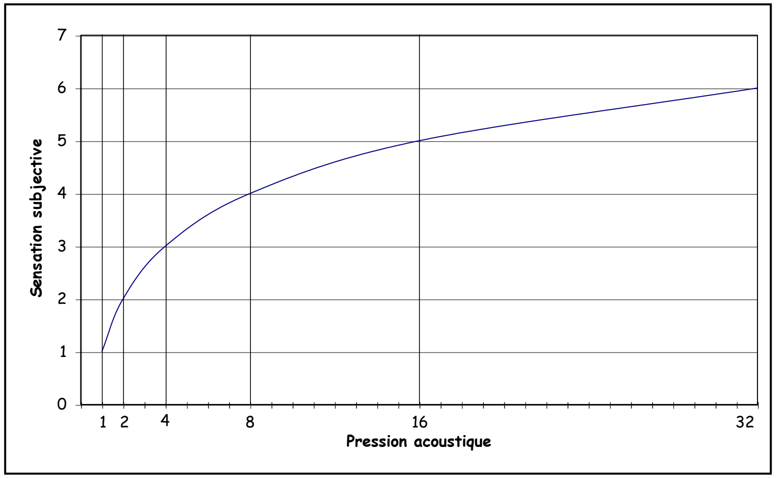
- **Most important equation** $$\lambda = c/f$$

- **air:** $c \approx 340\,\text{m/s}, \quad f = 1000\,\text{Hz} \quad \Rightarrow \quad \lambda = 0.34\,\text{m}$
- **water:** $c \approx 1500\,\text{m/s}, \quad f = 1000\,\text{Hz} \quad \Rightarrow \quad \lambda = 1.5\,\text{m}$

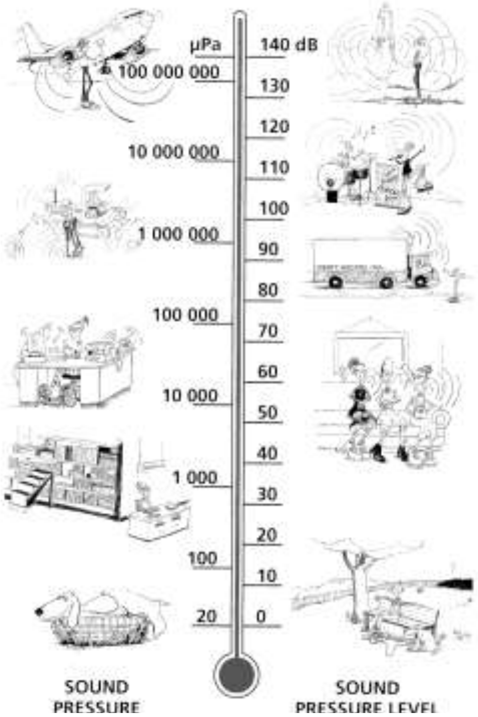


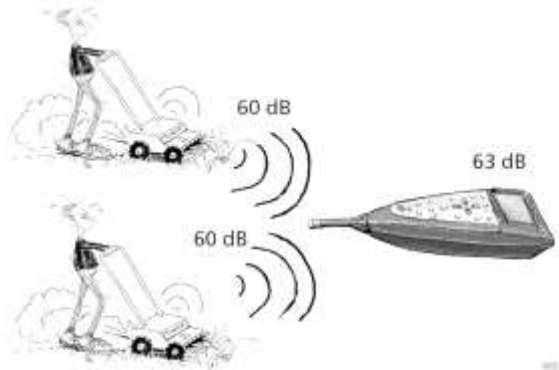
Sound Levels

- **The human perception of sound is not linear (Weber-Fechner law)**



- **The decibel (dB) is a logarithmic scale used to represent the human perception:** $SPL = 10 \cdot \log\left(\frac{P^2}{P^2_{ref}}\right)$
  - P: Acoustic Pressure
  - P_{ref}: Minimum perceptible acoustic pressure

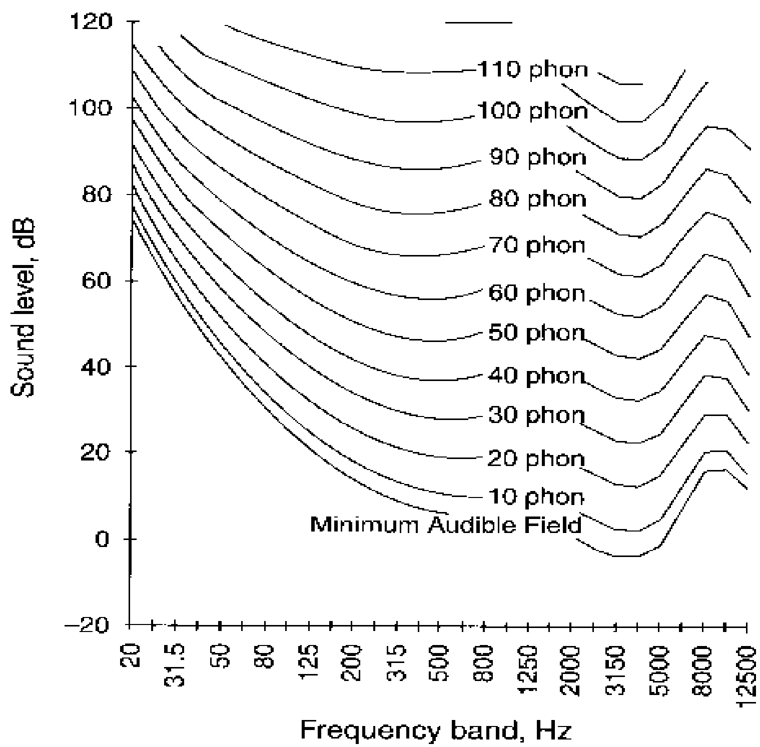




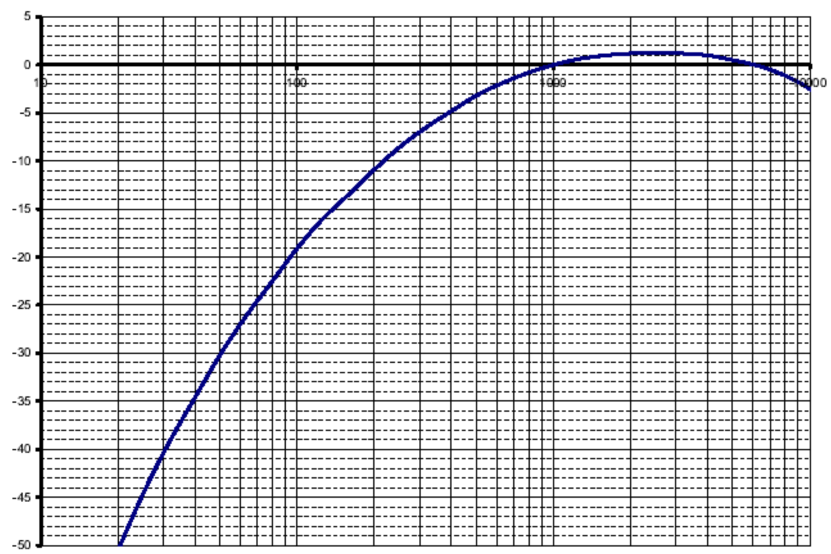
Phones and dB(A) Filters

- **The human ear does not perceive all frequencies in the same way ➔ filtering effect**

Fletcher and Munson curves (1933)

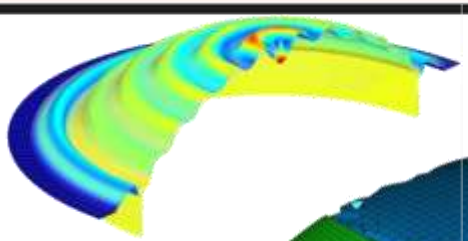


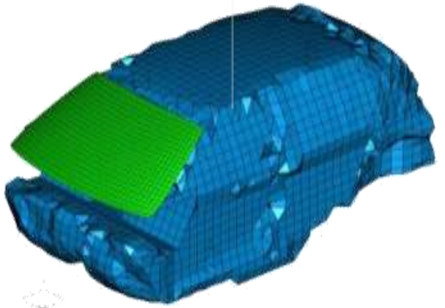
dB(A) filter

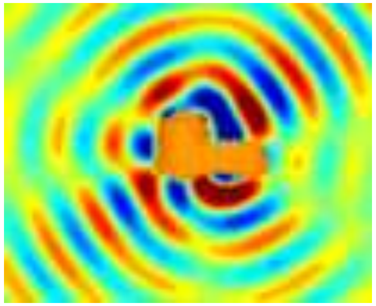


Vibro-Acoustics vs. Aero-Acoustics

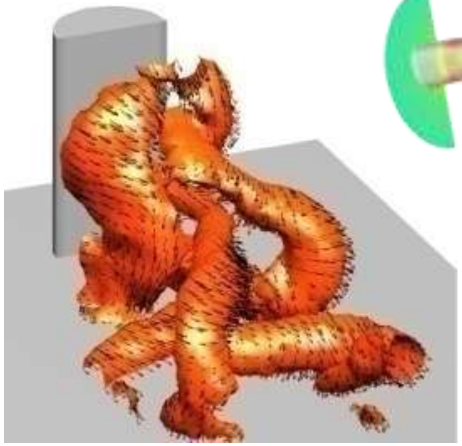
- **Vibro-acoustics**
  - Noise related to structures (vibration of structures, …propagation of sound through a structure)
  - Basically it covers the interaction of structures and fluids

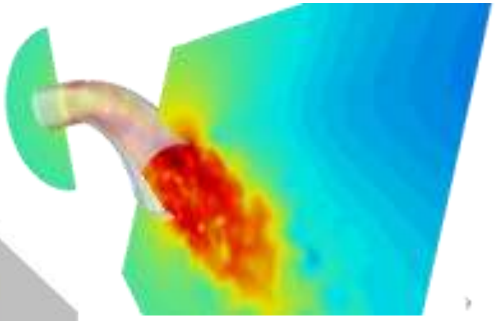




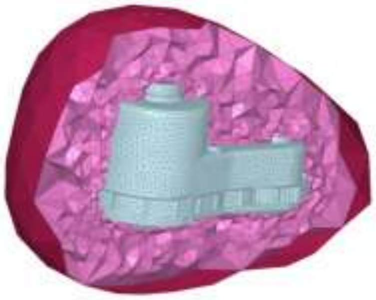


- **Aero-acoustics**
  - When the fluid dynamics lead to the generation of noise
  - Flow oscillations
  - Turbulence
- **Some problems can be aero-vibro-acoustics (ex. Side mirror noise)**

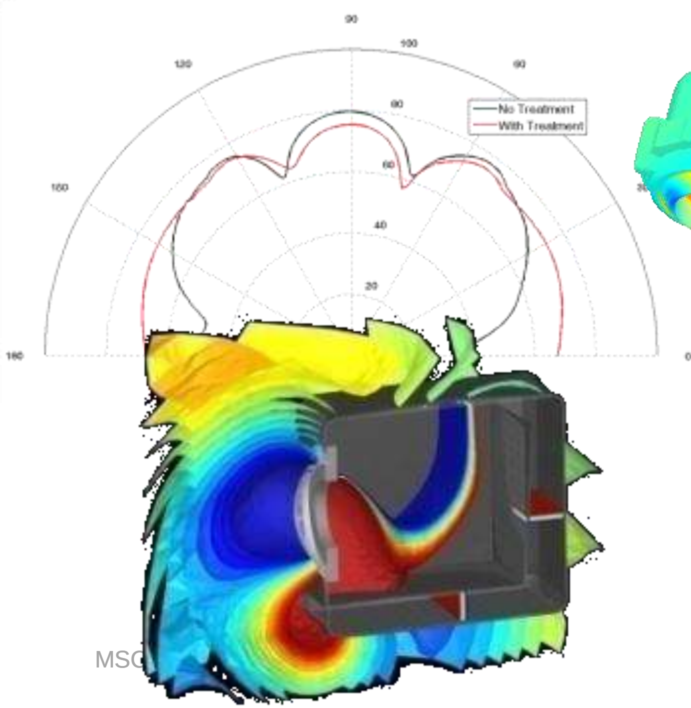


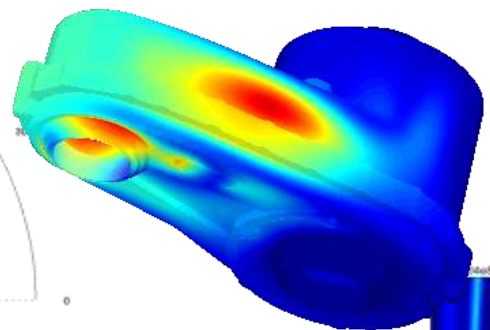


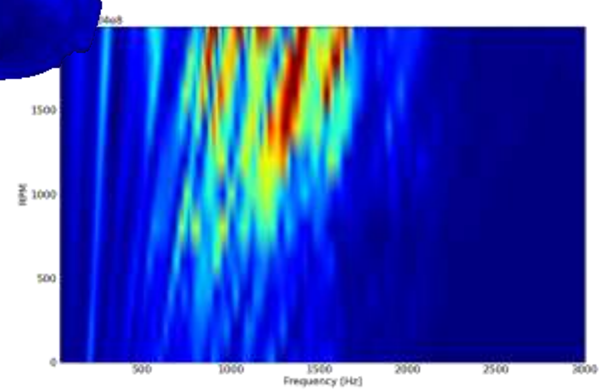
Typical Engineering Questions



- **Noise prediction**
  - Will there be a noticable sound radiation?
  - What is the expected sound pressure level (SPL)?
  - What are the resonant frequencies (= acoustic modes)?
  - Will the sound change with operating conditions?
  - How about directivity?

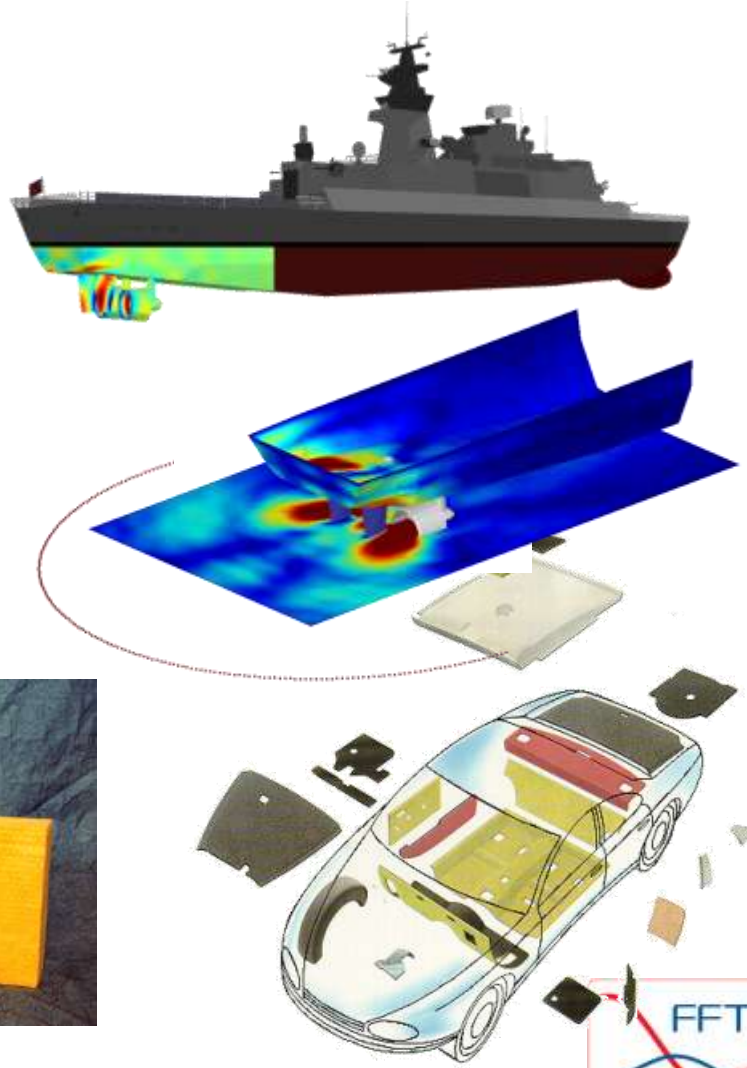


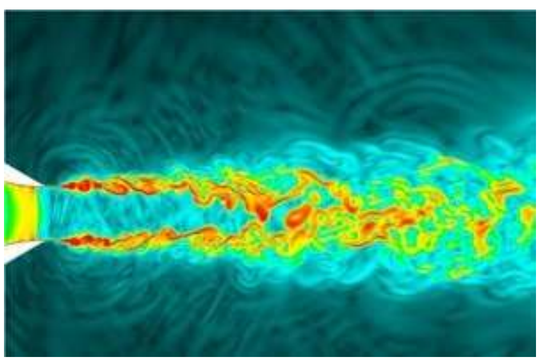




Typical Engineering Questions

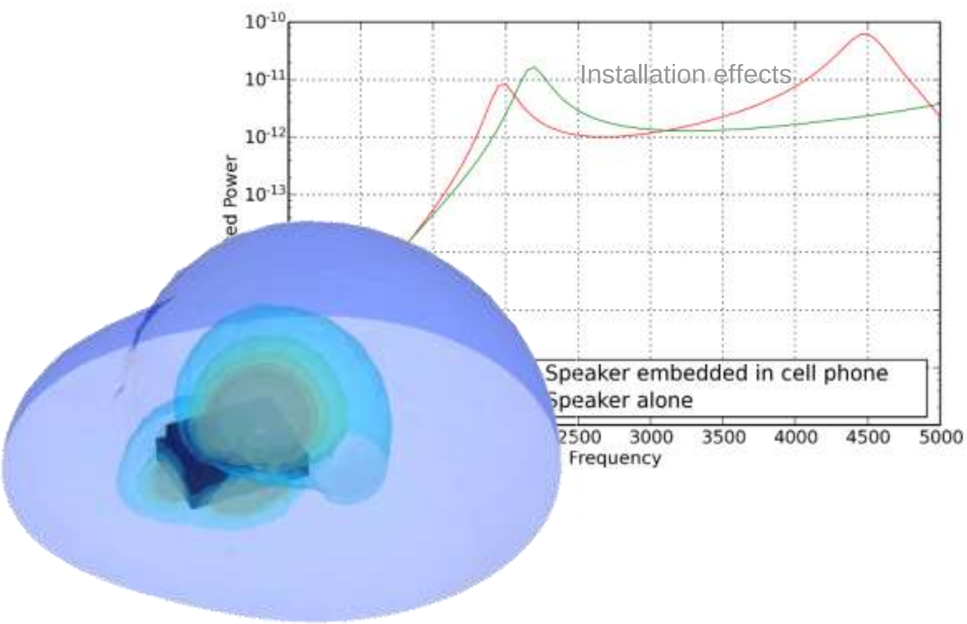
- **Noise reduction - what can we do to reduce the noise/ SPL?**
  - Geometrical changes?
  - Decoupling of parts?
  - Decrease sources /excitation?
  - Absorbing materials?
    - Foams, trims, multi-layer composites
  - Change the flow conditions?

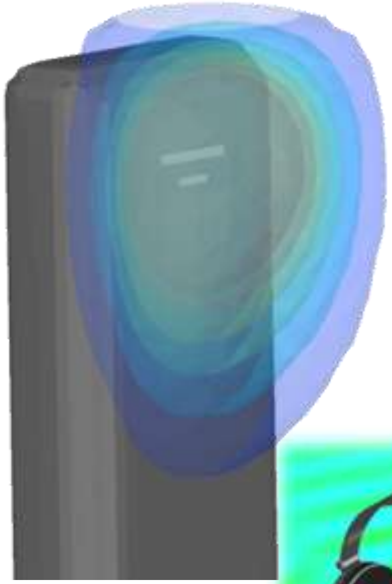


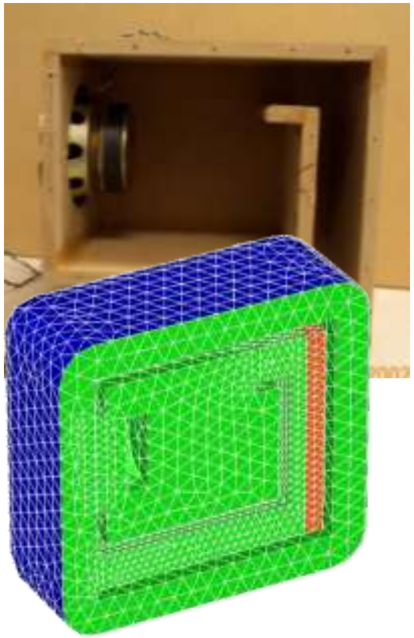


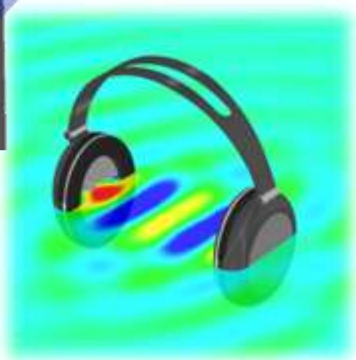
Typical Engineering Questions

- **Sound is not always a problem**
  - Efficient radiation of HiFi components
  - Sound design of consumer products, cars…
  - Musical Instruments







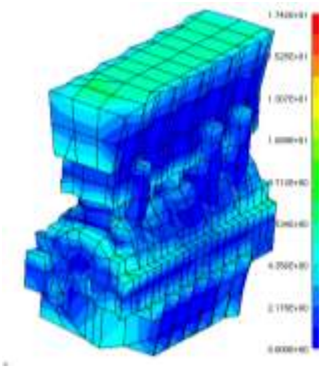


Introduction to Computational Acoustics

Key concepts

Boundary Elements

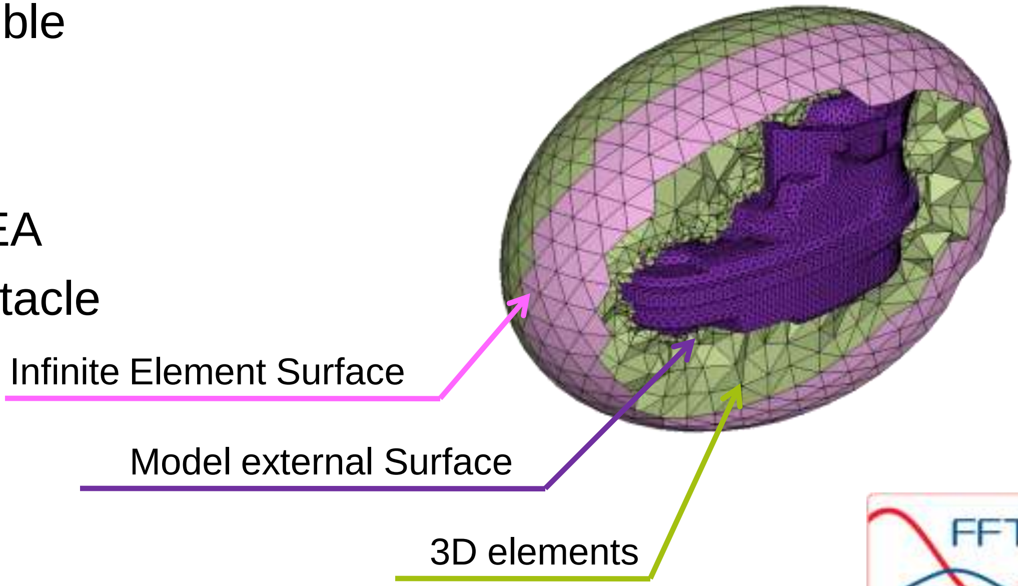
- **Early work on computational acoustics was based on the boundary element method.**



- **Motivations**
  - Easier meshing (surface only)
  - Lower number of degrees of freedom
- **Limitations**
  - Dense system of equations
    ➔ large computational costs (limit on the number of dof ~ 30.000)
  - Homogeneous domain:
    - no mean flow
    - no temperature gradient
    - no possibility to model interaction between air and absorbing material
  - Boundary Integral Equation theory is far from intuitive
  - Convergence & stability problems (“irregular frequencies”)
  - Coupling to structural FEA is difficult

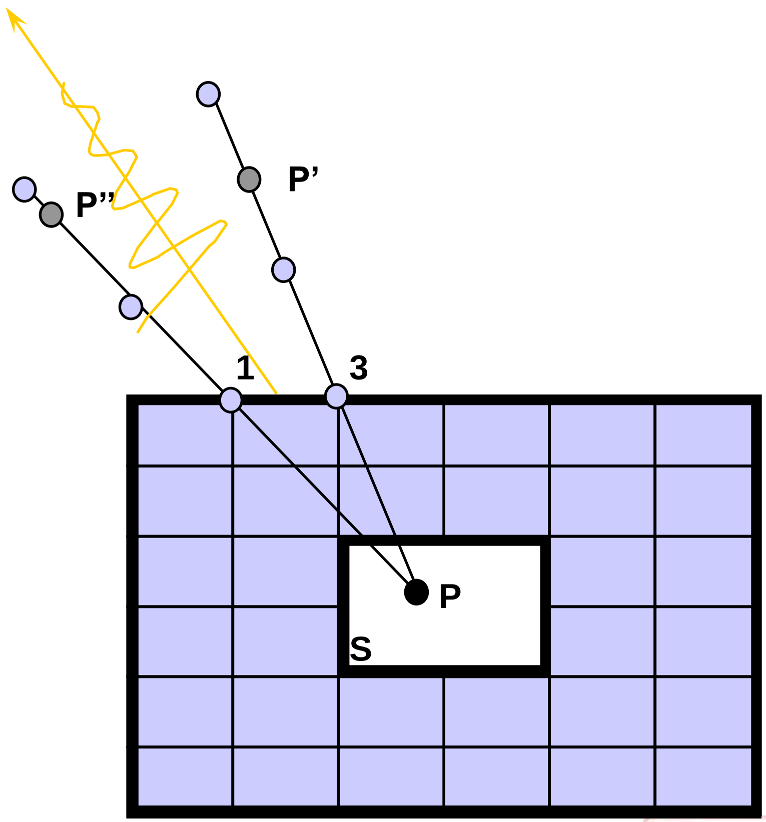
Finite Element Analysis

- **Benefits:**
  - FEA is known by all engineers
  - Sparse system of equations : FEA can handle very large models (millions of dofs)
  - Acoustic FEA couples easily with structural FEA
  - FEA is able to handle any mix of material and any non-homogeneity (temperature gradient, background flow)
  - Modal approaches are possible
  - FEA is faster than BEA
  - FEA is more flexible than BEA
  - Meshing is no longer an obstacle



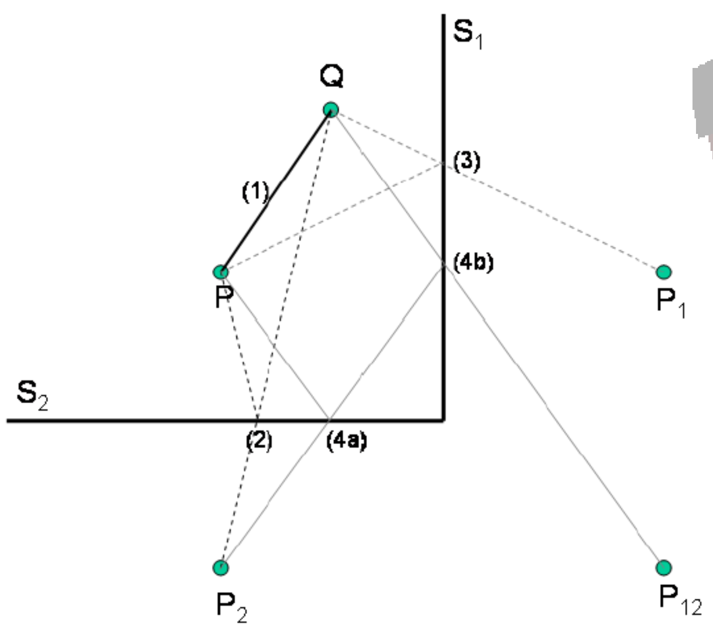
Infinite Elements

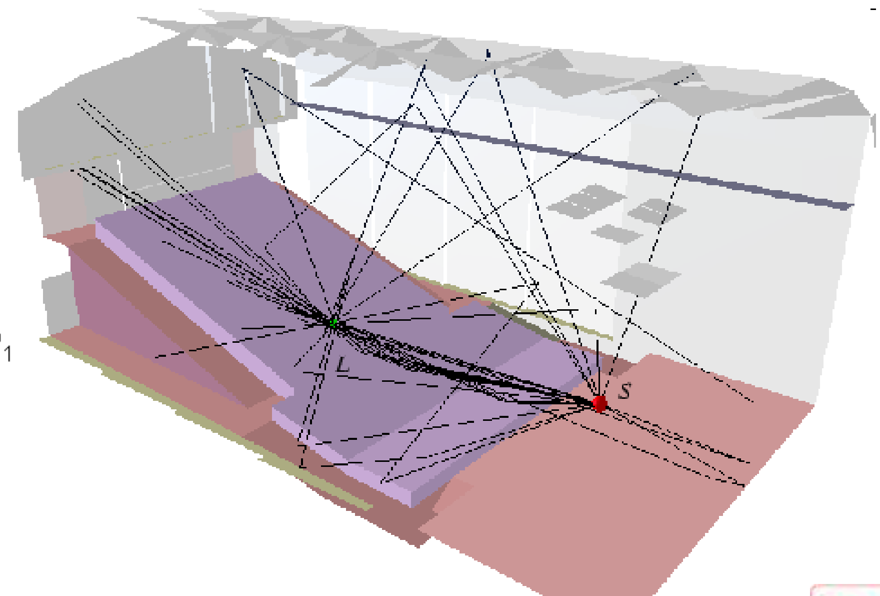
- **Infinite elements are:**
  - « finite » elements
  - covering an unbounded domain
  - with appropriate high order shape functions in the radial direction
- **Infinite elements:**
  - ensure there are no wave reflections at the FE/IE interface
  - provide accurate acoustic results beyond the FE domain



Ray Tracing Technique

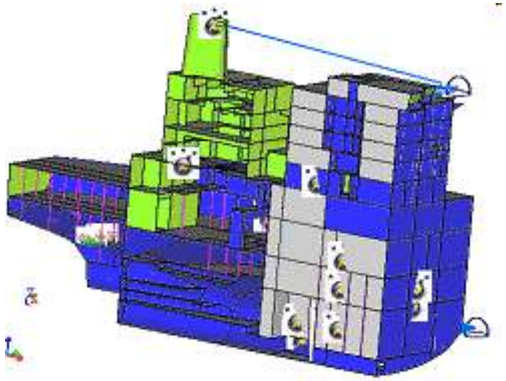
- Similar to optics : look at the path of the particles
- No diffraction nor resonance effects accounted
- Valid only for very large problems
- Mainly used for room or environmental acoustics



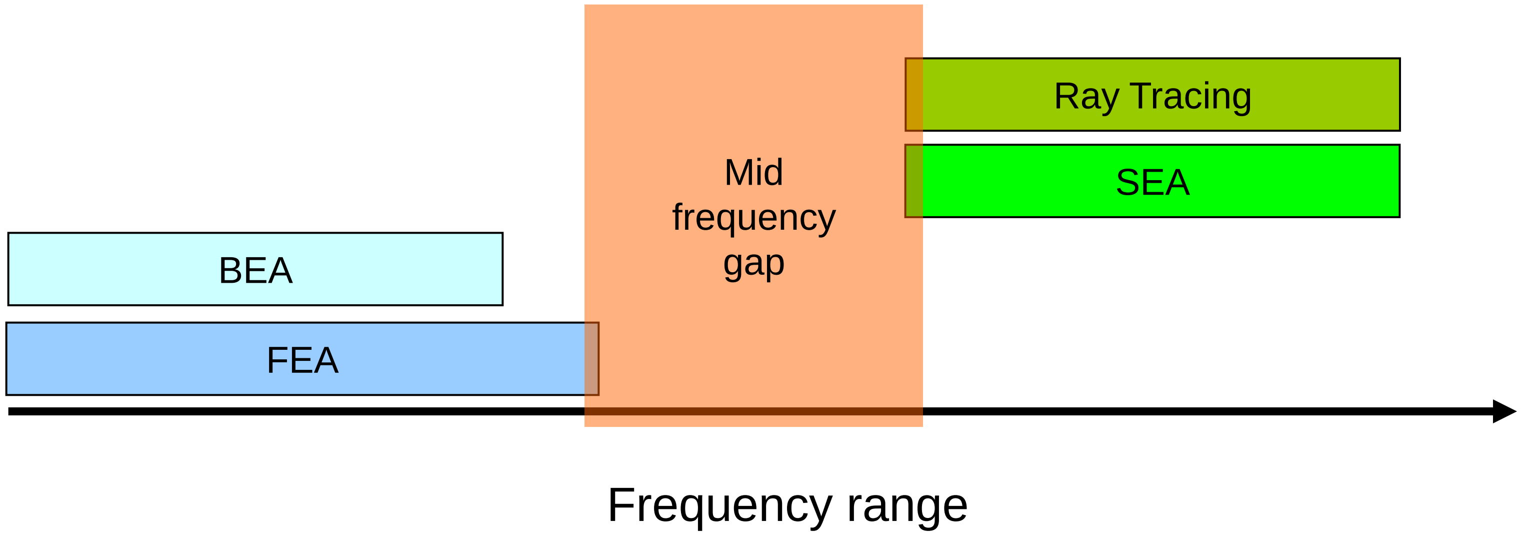


Statistical Energy Analysis

- **SEA is a high-frequency analysis method based on**
  - the decomposition of the structure into weakly coupled resonant subsystems.
  - space averaging (one dof per component)
  - frequency averaging (results are per frequency band)
- **An predictive SEA model is very difficult to build**



Frequency Range

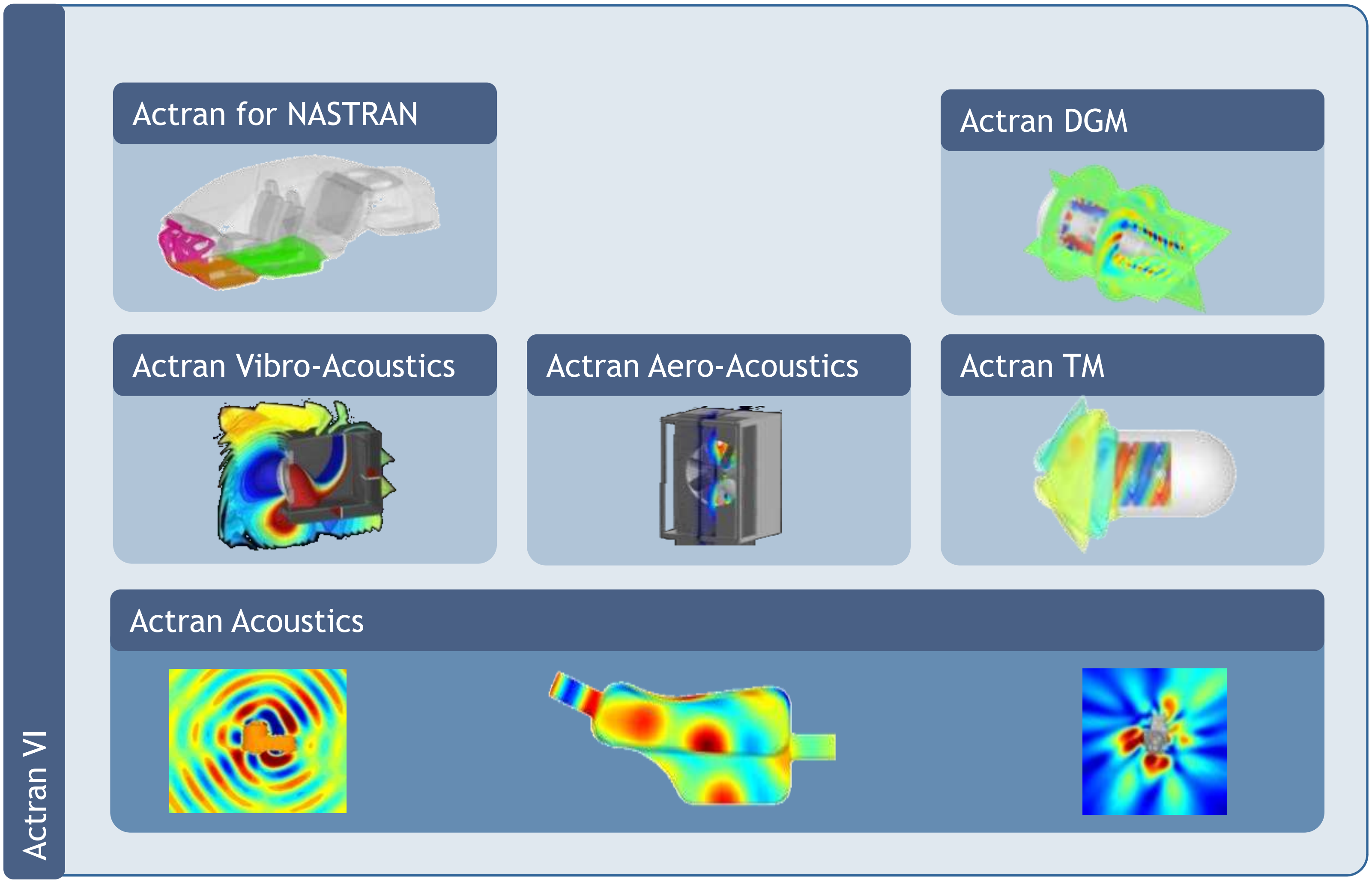


- **What is "low" frequency ? It depends on the application :**
  - Car engine ~ 3-5 KHz
  - Aircraft cockpit ~ 1-2 KHz
  - Loudspeaker ~ 5KHz
  - Mobile phone ~ 20KHz
  - Ship ~ 500 Hz

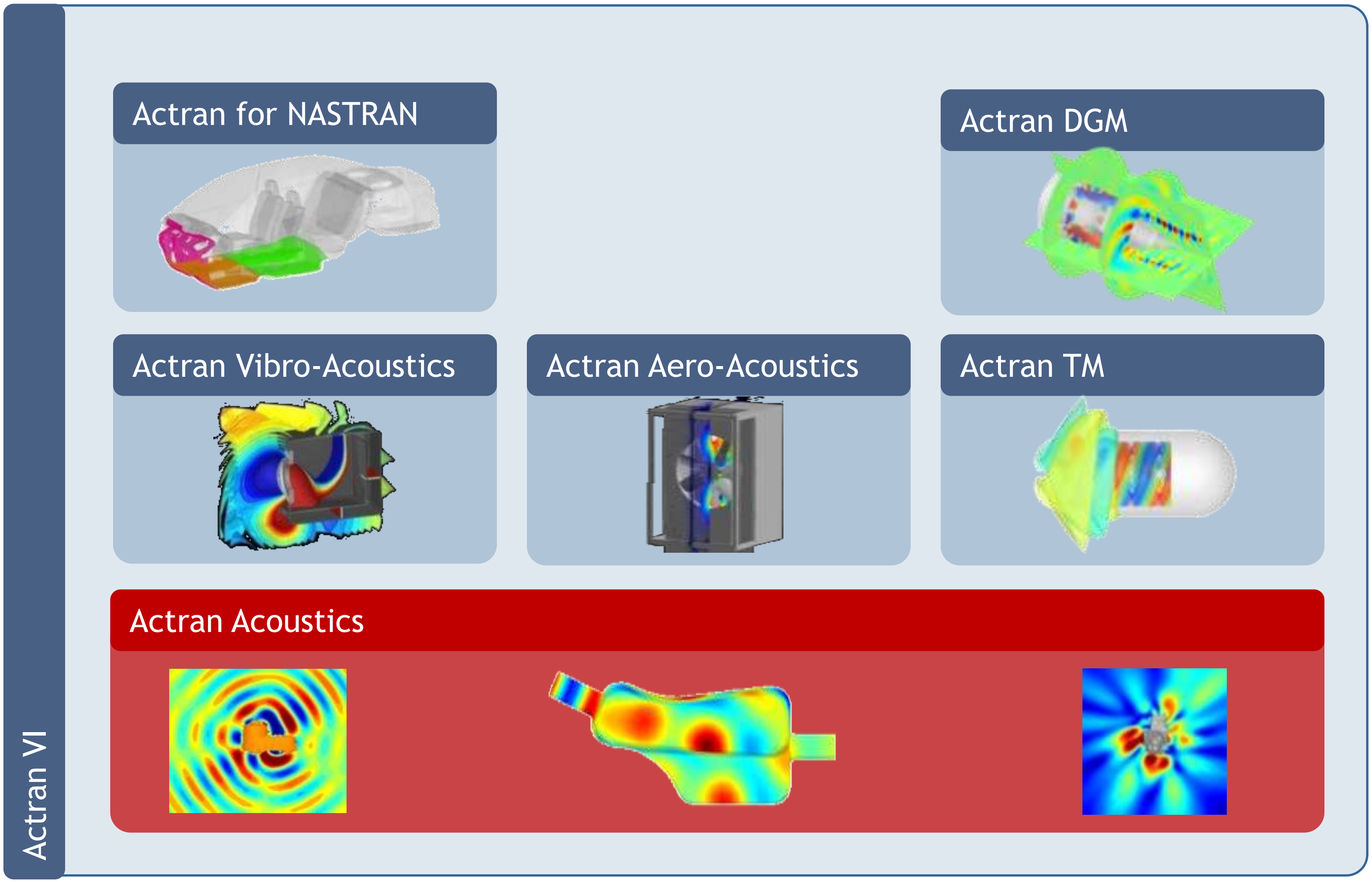
Introduction to Actran

Key concepts

The Actran software suite

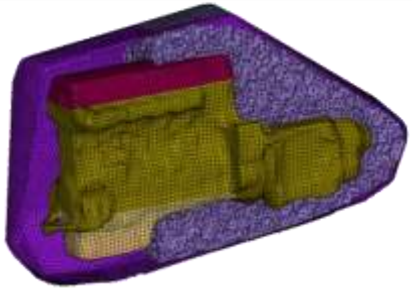


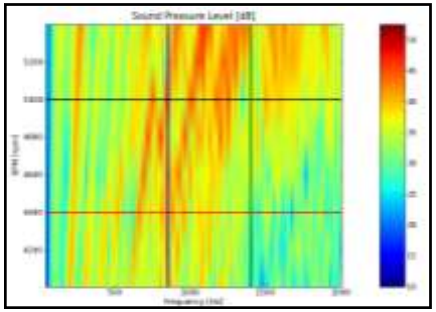
The Actran software suite

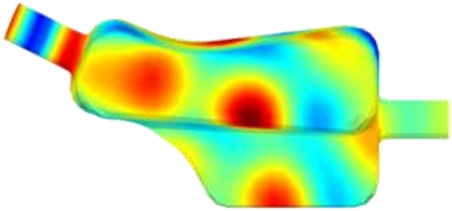


Actran Acoustics Features

- **Acoustics as well as weak vibro-acoustic coupling**
  - Acoustic finite elements, infinite elements & PML
  - Including visco-thermal loss effects
  - Convected wave propagation (flow + temperature)
- **Excitations imported from MSC Nastran or others**
- **Results provided (among others)**
  - Acoustic pressure, intensity and power
  - Power distribution and radiation efficiency
- **Applications**
  - Exterior acoustics : any vibrating / radiating component : e.g. power train, gear box, oilpan or others
  - Interior acoustics
  - Ducted acoustics : intake & exhaust systems
- **Can be further extended using vibro-acoustics and aero-acoustics features**



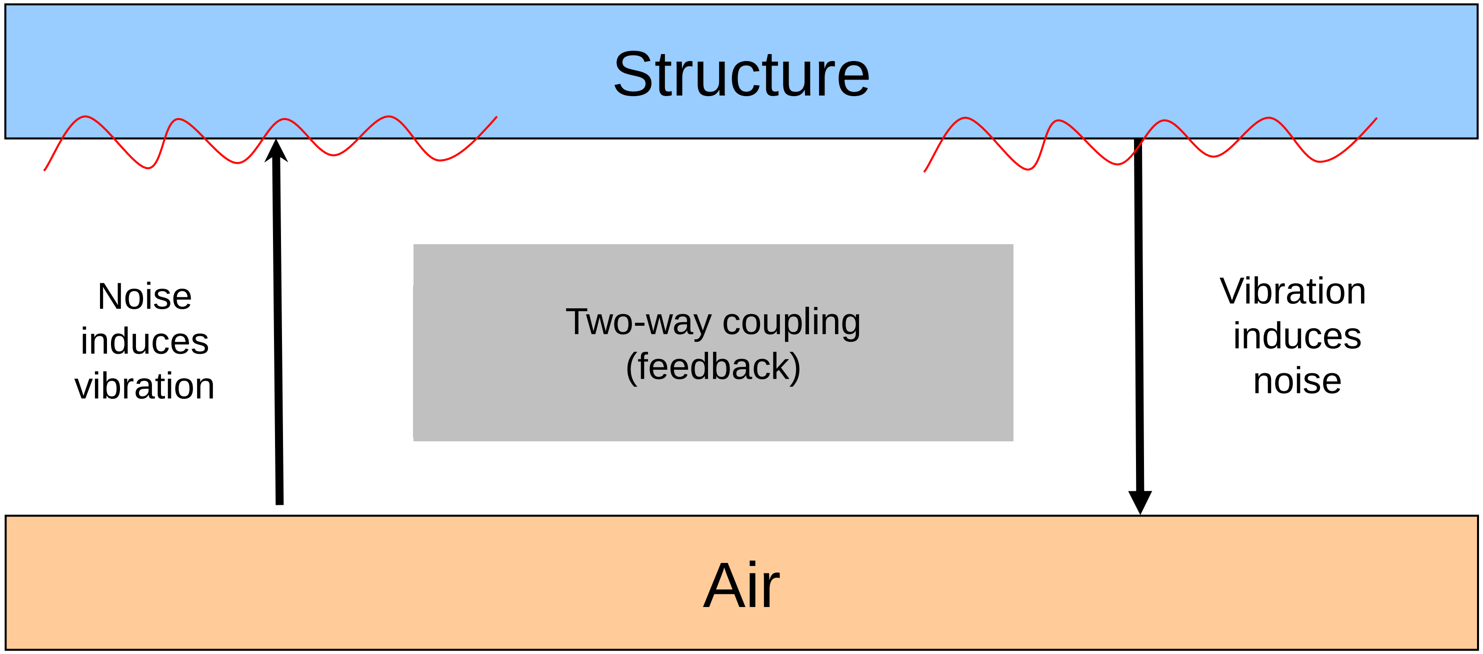




FFT
An MSC Software Company

Acoustic Radiation

Vibro-Acoustics - One-Way or Two-Way Coupling



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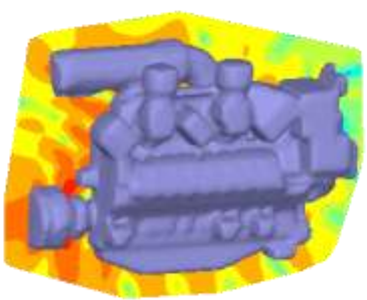
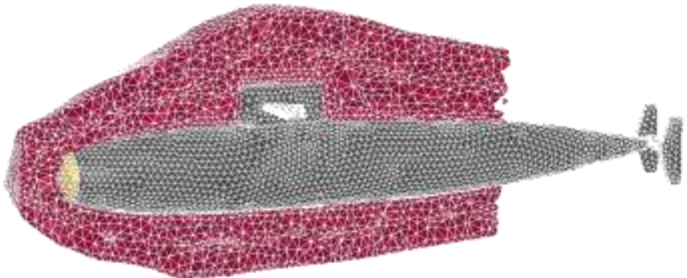


Engine radiating in free field

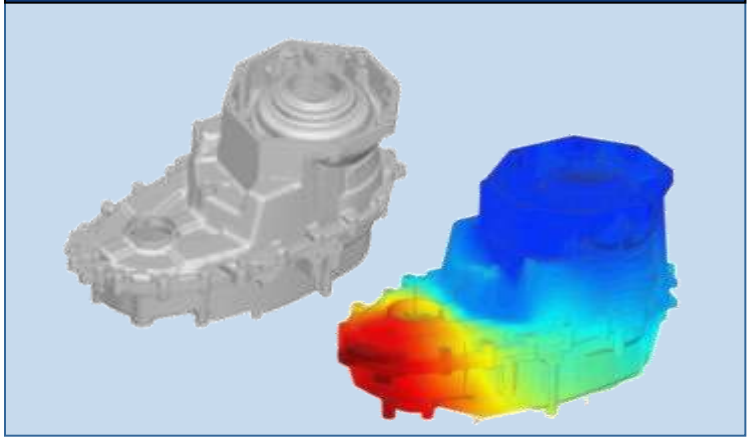
KO



Sub-marine under water

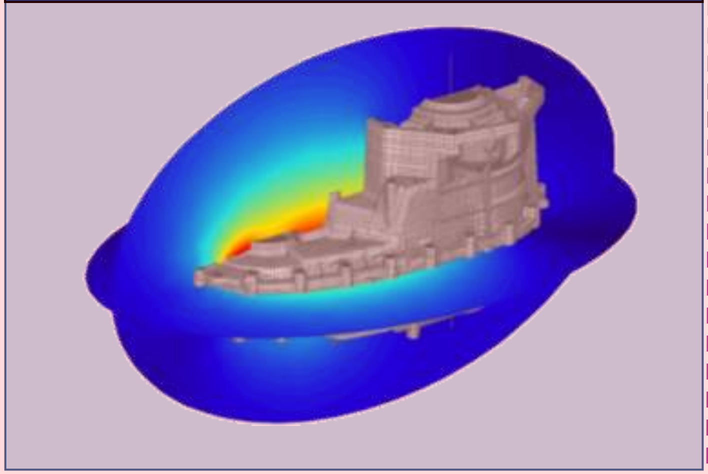
Computation Process

1. Structural FEA Analysis = MSC Nastran



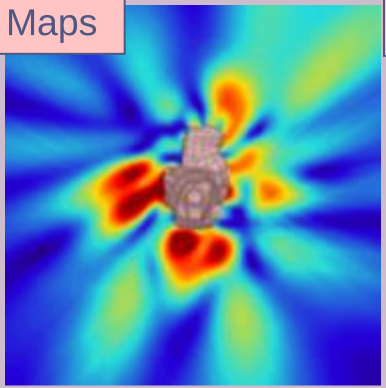
Mesh & results files

2. Acoustic computations = Actran



3. Post Processing and Analysis = Actran VI

Maps



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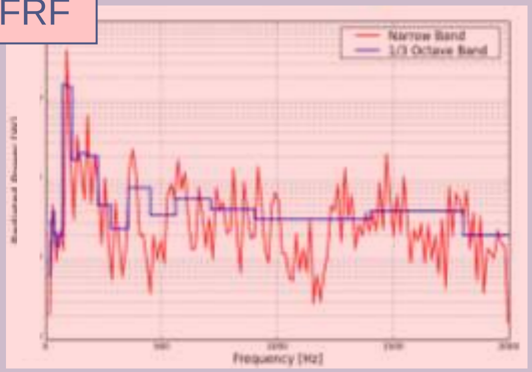
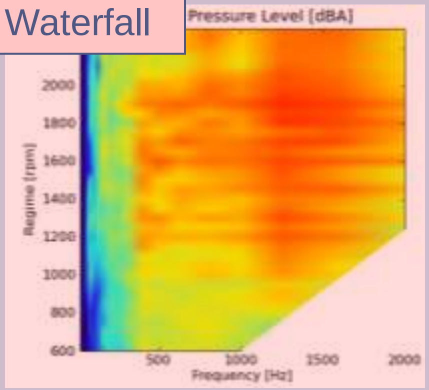


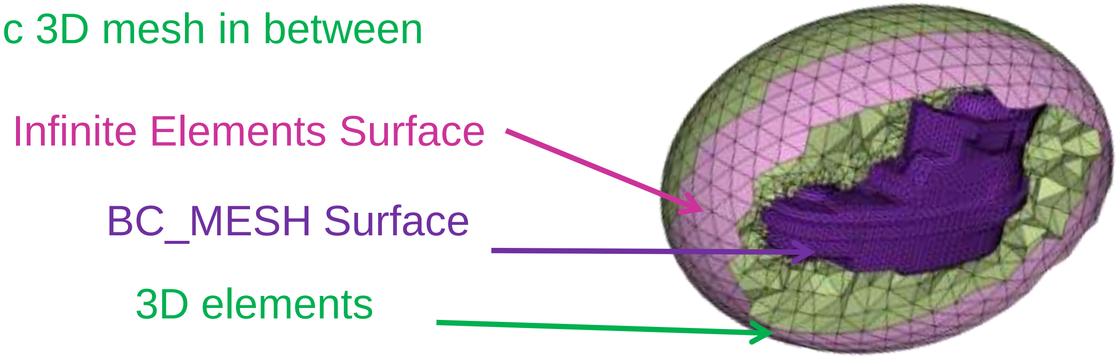
Waterfall



Preparation of the Acoustic Mesh

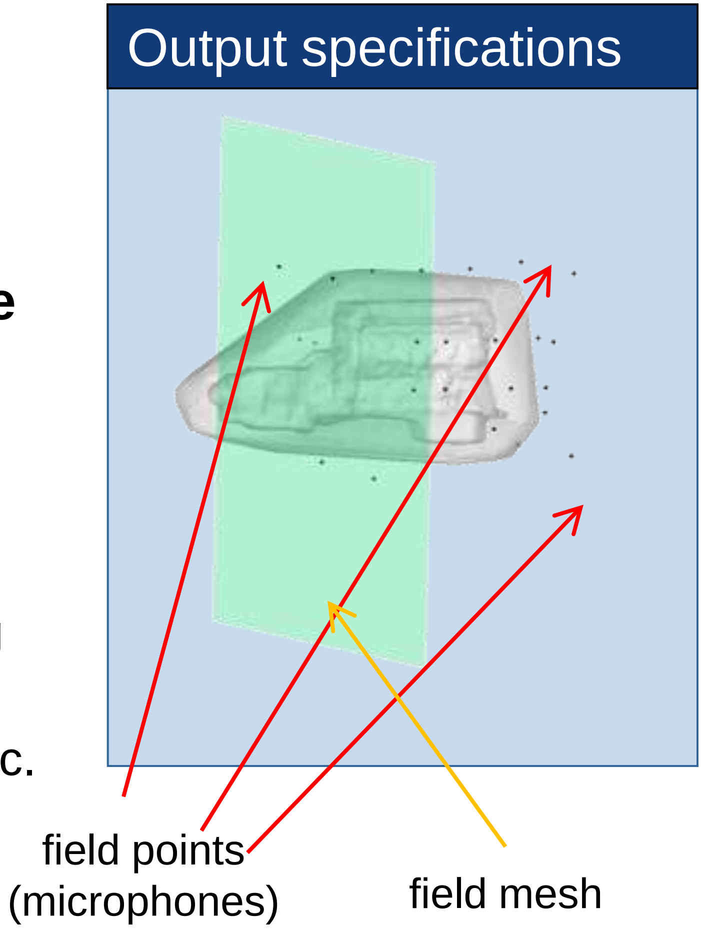
- **A 3D finite element mesh is a requirement to support the acoustic analysis**
- **The element size must be small enough to capture the smallest acoustic wavelength** $\lambda = c/f$

  ➔ use of 4 linear element per wavelength thanks to optimized integration rules
- **The meshing process is easy**
  - Create a closed surface mesh (BC_MESH) very close around the structural model (wrapping)
  - Create a surface mesh at a distance D (~0.3 x size of object) of the structure to support the infinite elements
  - Automatic 3D mesh in between



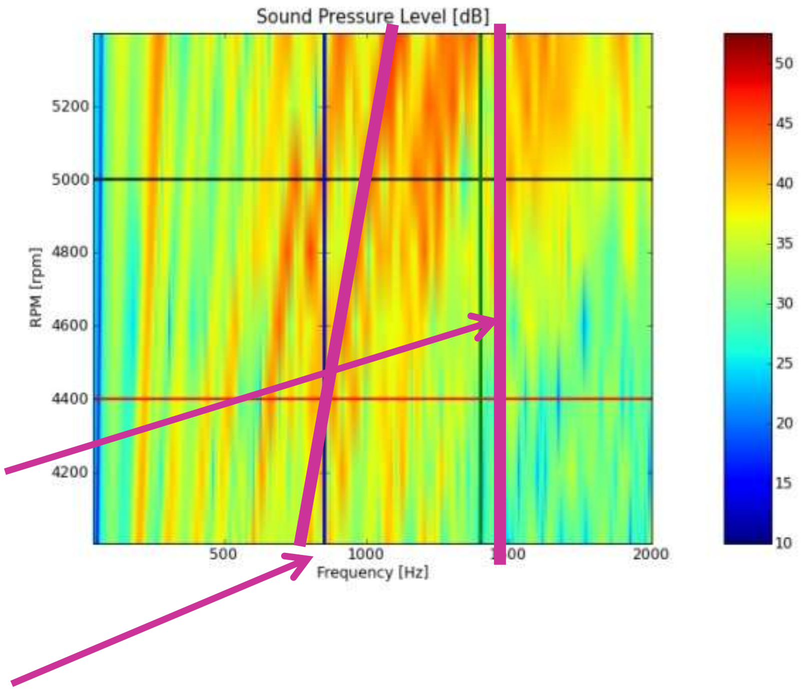
Results – Output Specification

- **Virtual microphones can be located anywhere in the finite and/or infinite element domain**
- **Multiple control surfaces to compute the radiated power**
- **Maps for different frequencies**
  - on the acoustic mesh or/and
  - on a mesh dedicated to the post-processing (named field mesh in Actran)
  - plot acoustic pressure, acoustic intensity, etc.



Waterfall Diagrams

- **“Waterfall” are diagrams where the response is plot versus both frequencies and the engine orders (RPM)**
- **Such diagram can be obtained after a single Actran computation thanks to the <u>multi-load case</u> capability**
- **Some phenomena can be identified as <u>system dependent</u> (vertical lines on the waterfall), e.g. structure modes, …**
- **Some phenomena can be identified as <u>excitation dependent</u> (diagonal lines on the waterfall)**



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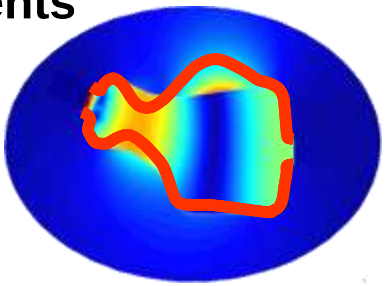
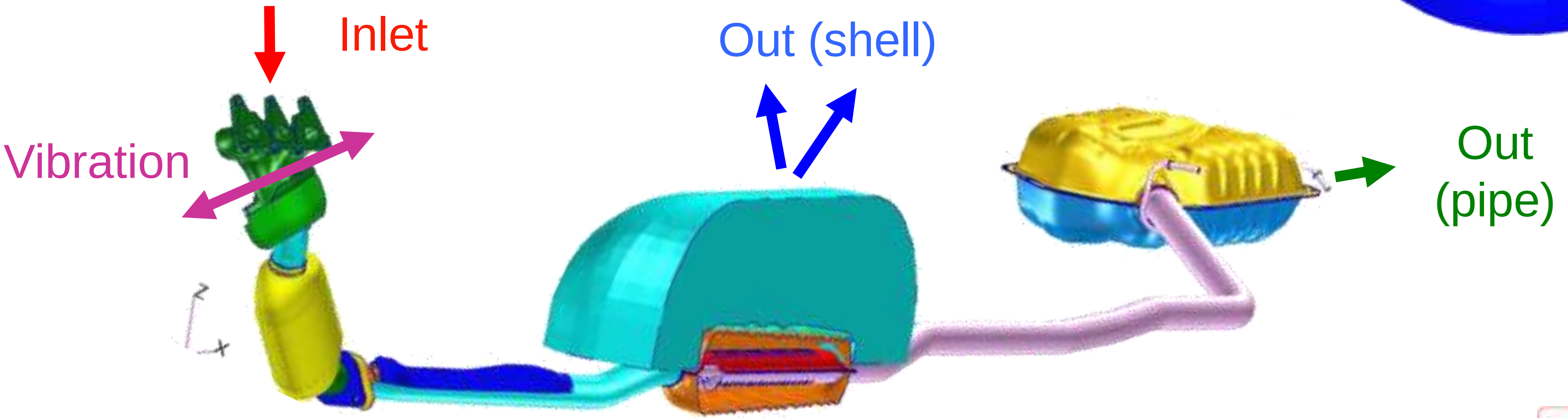
Exhaust Pipe Noise

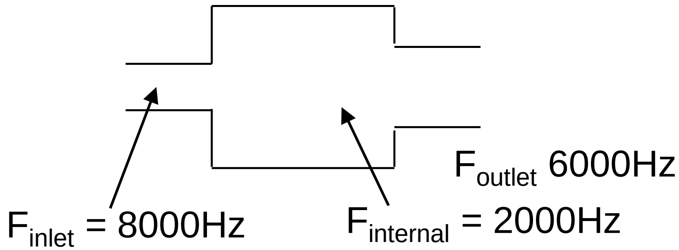
Exhaust Noise : Problem Statement

- **Two major components for intake or exhaust noise**
- **Tail Pipe Noise = Noise radiated by the outlet**
  - Source = engine pulse
  - Propagation = **air-borne** – ducted acoustics
- **Shell Noise = Noise radiated by the shell of major components**
  - Source = engine vibration
  - Propagation = **solid-borne** – coupled vibro-acoustics
- **Interactions/coupling between the two contributions**

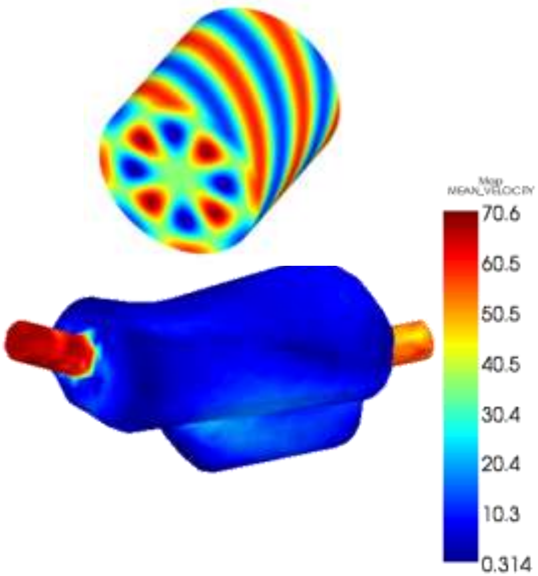




Actran Features for Pipe Noise



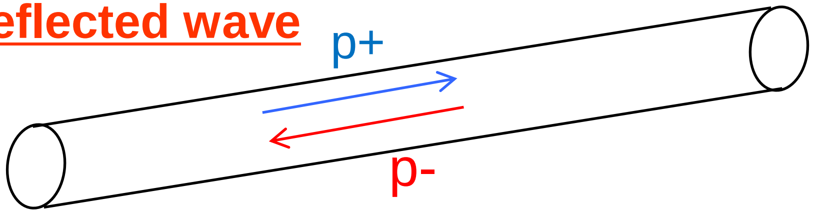
- **3D finite element solver**
  - Not limited to low frequencies or small sections
  - Not limited to simple shapes
- **Acoustic duct modes**
  - Represents semi-infinite ducts
  - Mandatory to split into sub-problems
  - Can be fed with 1D RANS solvers
- **Infinite Elements for the free field radiation (pipe)**
- **Compatible with heterogeneous media**
  - Import a temperature and a flow field
- **Porous elements to represent absorbing materials**
- **Formulation for perforated plates (Mechel)**
- **Transfer Matrix Method to split the entire line into components**



What are Duct Modes ?

- Any acoustic wave that propagates inside a duct can be decomposed into an incident wave and a reflected wave

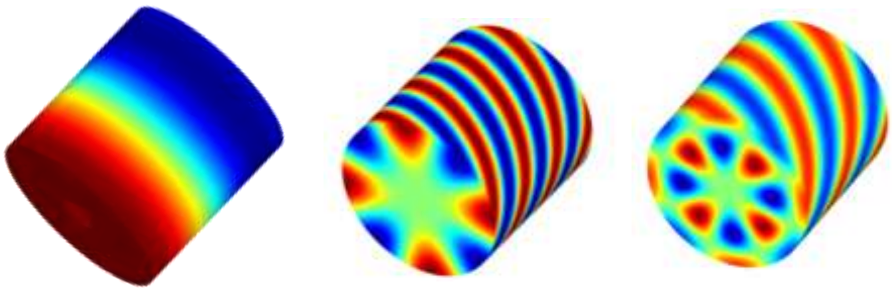
$$p = p^{+} + p^{-}$$



- In any case, the pressure can be seen as a mathematical superposition of duct modes (this is an exact representation)

$$p^{+} = \sum_{propagating\ modes} \alpha_i^{+} \psi_i^{+}$$
$$p^{-} = \sum_{propagating\ modes} \alpha_i^{-} \psi_i^{-}$$

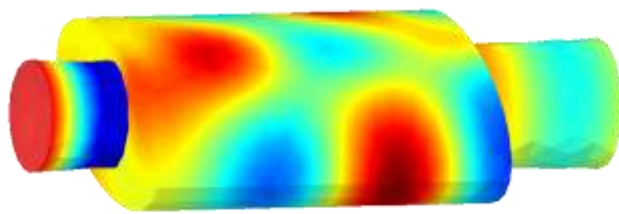
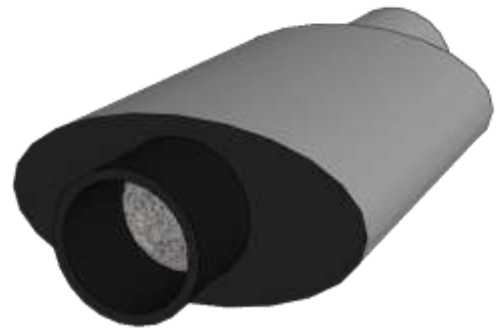
α_i= participation factor
Ψ_i= mode shape



- At low frequencies and/or small sections, only plane wave
- At high frequencies and/or large sections, the acoustic field can be more complex

Duct Modes – Application for exhaust

- **Evaluate the acoustic transmission (Transmission Loss) through an exhaust (or intake line) of any of its component**

- **The duct modes will be used**
  - At the inlet to represent the incident (imposed) and reflected (free) waves
  - At the outlet to represent the transmitted (free) wave

- **These simulations typically involve <u>only the plane duct mode</u> at inlet and outlet, because the sections are small and the higher order modes are cut-off (evanescent)**

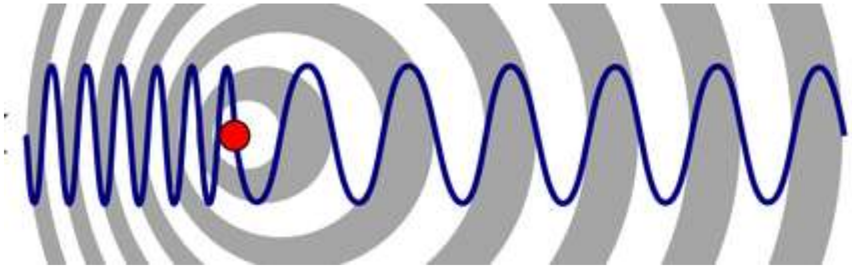
Flow & Thermodynamic Heterogeneities

- **A temperature, pressure or density field impacts the local sound speed**

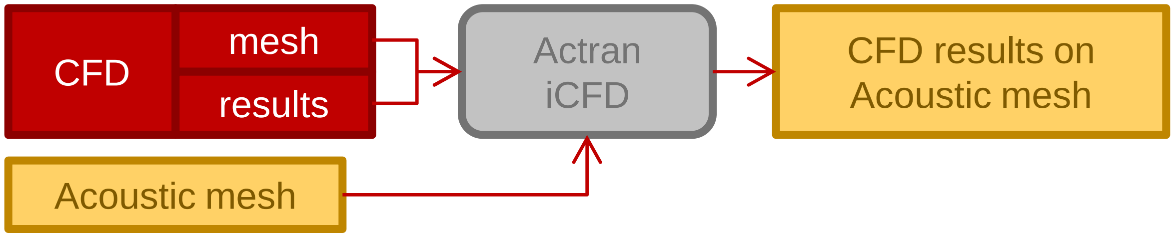
$$c(x) = \sqrt{\gamma R T(x)} = \sqrt{\frac{\gamma p(x)}{\rho(x)}}$$

- **A mean flow modifies the acoustic waves propagation (i.e. Doppler Effect)**

$$\lambda(x) = \frac{c(x) \pm v_0(x)}{f}$$



- **Process**
  1. compute the aerodynamic field with CFD analysis (RANS, Euler)
  2. Project the quantities using Actran ICFD

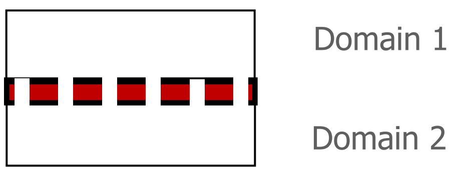


  3. Run the acoustic computation

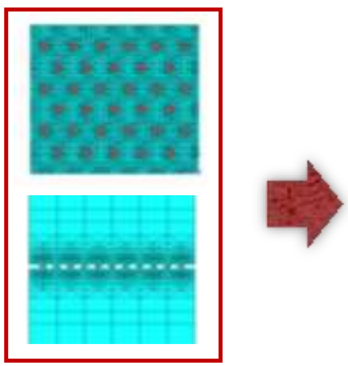
Model Perforated Plates (1)

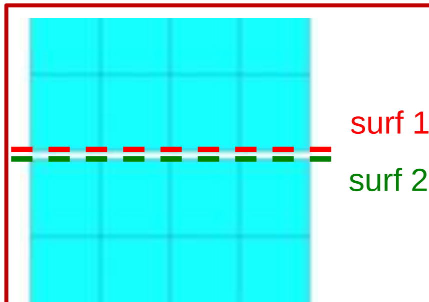
- **Goal : model problems involving acoustics domains separated by rigid porous sheets (grid)**

Eg. Perforated surfaces in mufflers



- **Method**
  1. Replace 3D model by two separated acoustic cavities with a transfer admittance





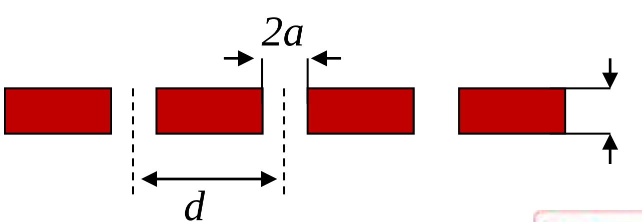
&

Characteristic transfer admittance matrix

$$\begin{bmatrix} v_{n1} \\ v_{n2} \end{bmatrix} = \begin{bmatrix} A_p & -A_p \\ -A_p & A_p \end{bmatrix} \begin{bmatrix} p_1 \\ p_2 \end{bmatrix}$$

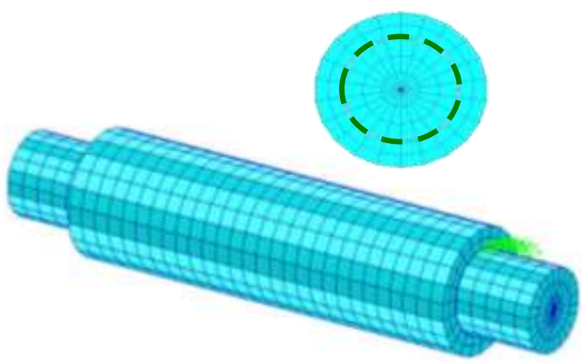
  2. Computation of A_p : use of Mechel's formula

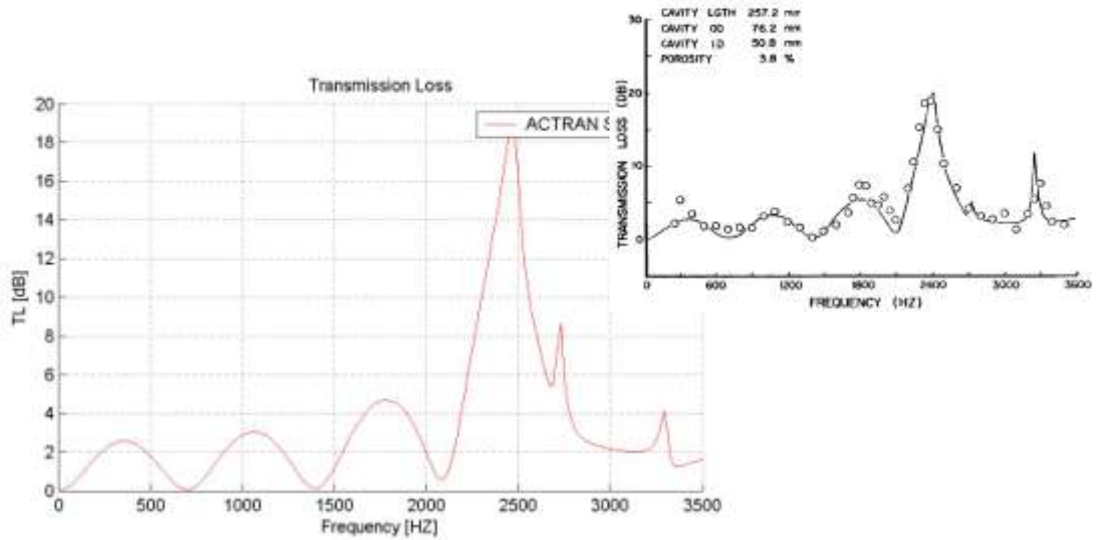
     A_p= function (fluid prop, geometrical prop)



Model Perforated Plates (2)

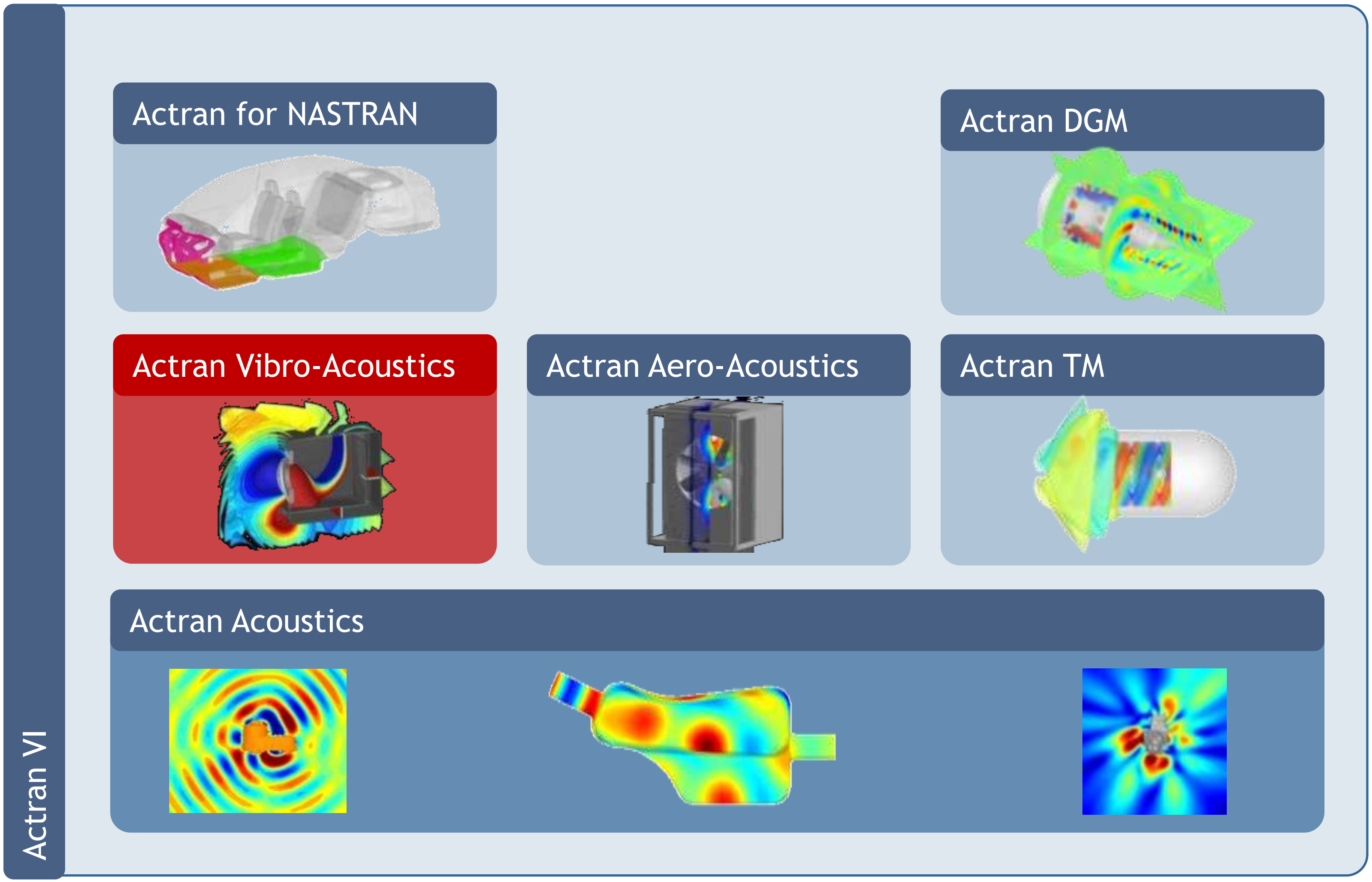
- **Advantages of the Mechel's Formula**
  - Meshing the holes = sometimes time consuming ➔ Mesh time reduction ☺
  - Modeling the holes = fine mesh required ➔ Coarser mesh allowed, thus CPU time reduction ☺
  - The Mechel's formula takes into account the dissipation through viscous effects in the holes vicinity
  - Evaluation of the power dissipation throughout the grid
- **Validation**





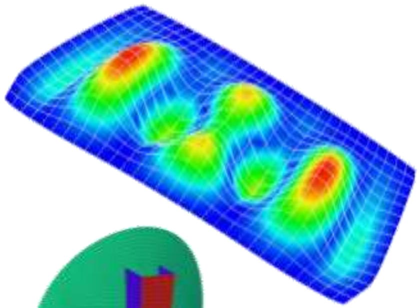
Ref: Sullivan and Crocker [*Analysis of concentric-tube resonators having unpartitioned cavities*, JASA, July 1978, Volume 64, Issue 1, pp. 207-215]

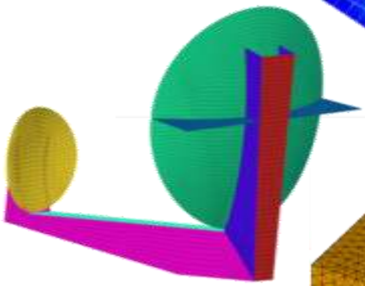
The Actran software suite

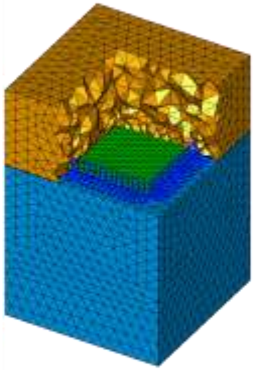


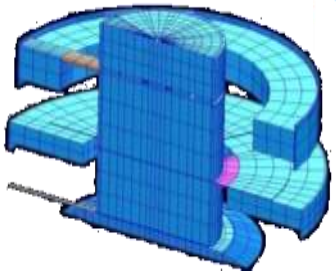
Vibro-Acoustics Elements Library

- **Acoustic elements**
  - Can support an heterogeneous medium (a flow field and/or a temperature field, for example)
  - Infinite elements
- **Shells & solids**
  - Visco-elastic shells, porous materials, see later
  - Visco-elastic solids
  - Piezo-electric elements (electric excitation, mechanical response)
  - Stiffeners, beams and mass-spring systems
- **Automatic computation of local/global indicators**
  - displacement, acceleration, stress
  - mean square velocity, dissipated energy
  - Automatic energy balance statements



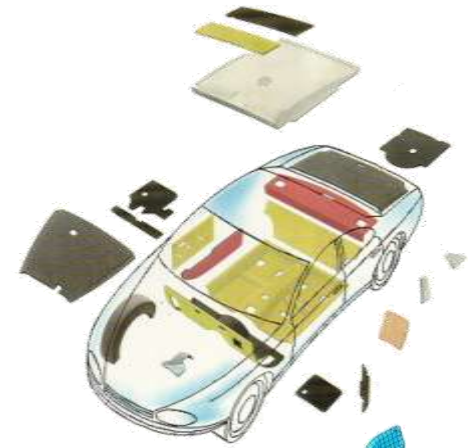


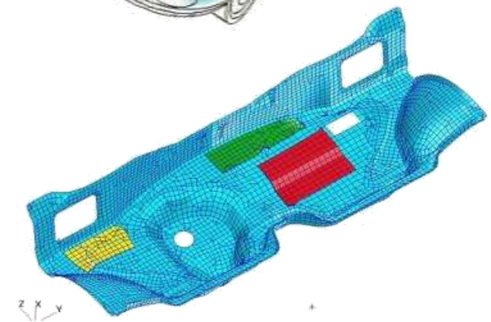




Porous Materials

- **Model foam, rock wool, fibers...**
- **Porous elements: based on Biot model**
  - Most complete : Porous UP Model
    - Vibrating skeleton surrounded by a fluid
    - 3 + 1 = 4 degrees of freedom per node
  - Other more simple models : Delaney-Bazley, Miki, Rigid porous, Lump porous
  - Material properties (frequency dependent):
    - Foam skeleton properties : Young modulus, density, Poisson ratio
    - Fluid properties : fluid density
    - Foam properties : tortuosity, resistivity, porosity, …
- **Local & global indicators**
  - displacement, pressure…
  - dissipated energy in each layer or each material or any specific area defined by the user





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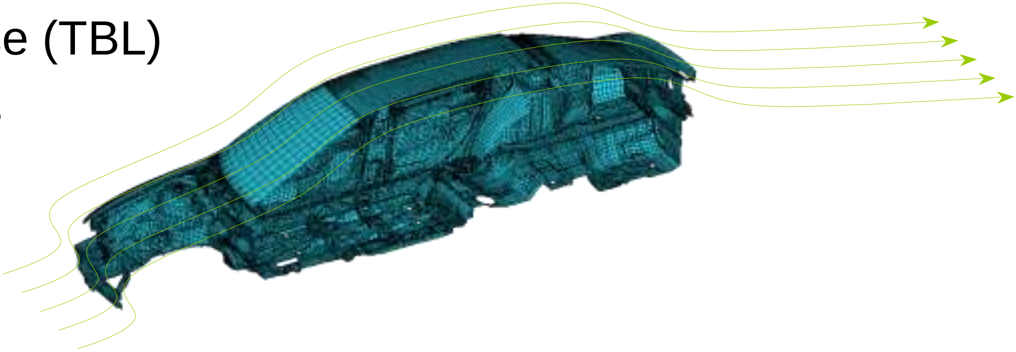
Excitations

- **Standard excitations**
  - Point loads, displacements
  - Monopoles, plane waves, etc
  - Distributed loads
  - Electric excitations (piezo)

- **Random excitations (random fields)**
  - Diffuse sound field
    - → Model reverberant room experiments
  - Turbulent Boundary Layer noise (TBL)
    - → Corcos, Goody and others
  - Delta correlated excitation
    - → Model Rain-on-the-roof

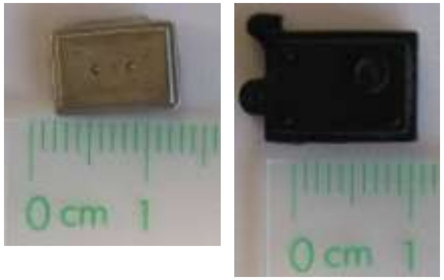


- **Import from FEA or CFD**

Application Review: Loudspeaker for Cell Phone - Model

- **Key ingredients**
  - Visco-elastic shells for the **membrane + copper + cover**
  - Acoustic finite elements for the **interior air** and near field **exterior** + infinite elements for the far field
  - Visco-elastic solids for the **rubber protection**
- **Distributed constant excitation on the copper layer attached to the membrane**
- **Computational sequence = direct frequency response**

Loudspeaker



Actran mesh for installation effect

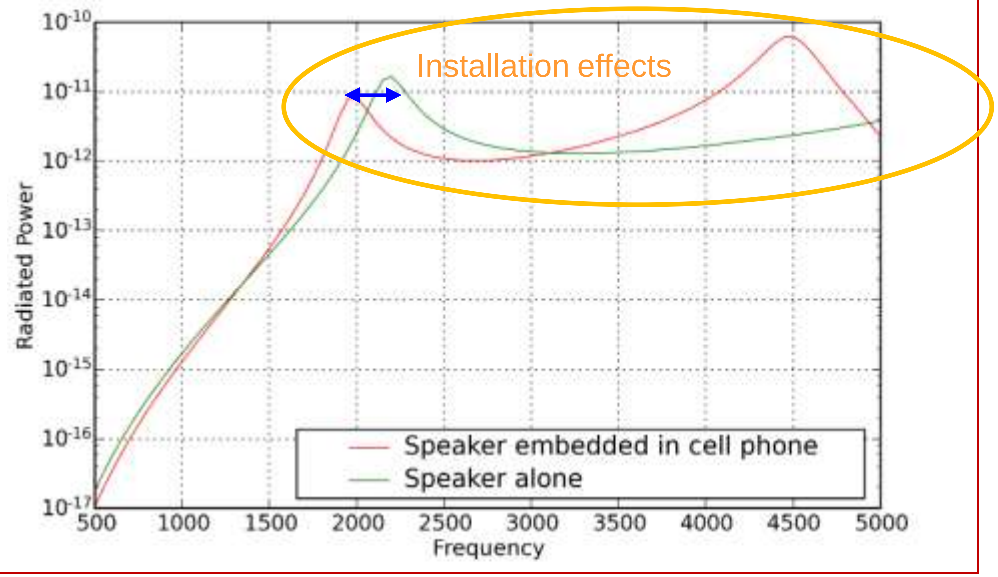
Interior mesh

Cell phone cover mesh

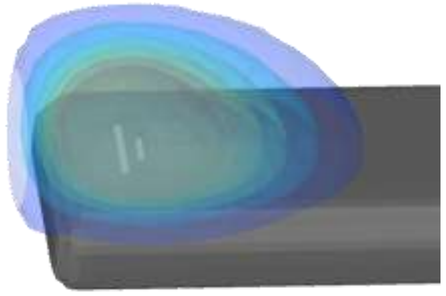
Exterior mesh

Application Review: Loudspeaker for Cell Phone - Results

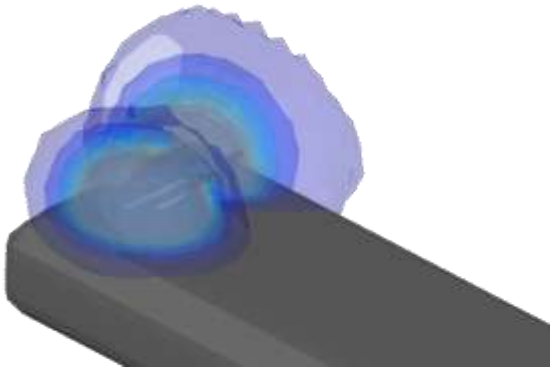
Transfer Function Radiated Power/Excitation



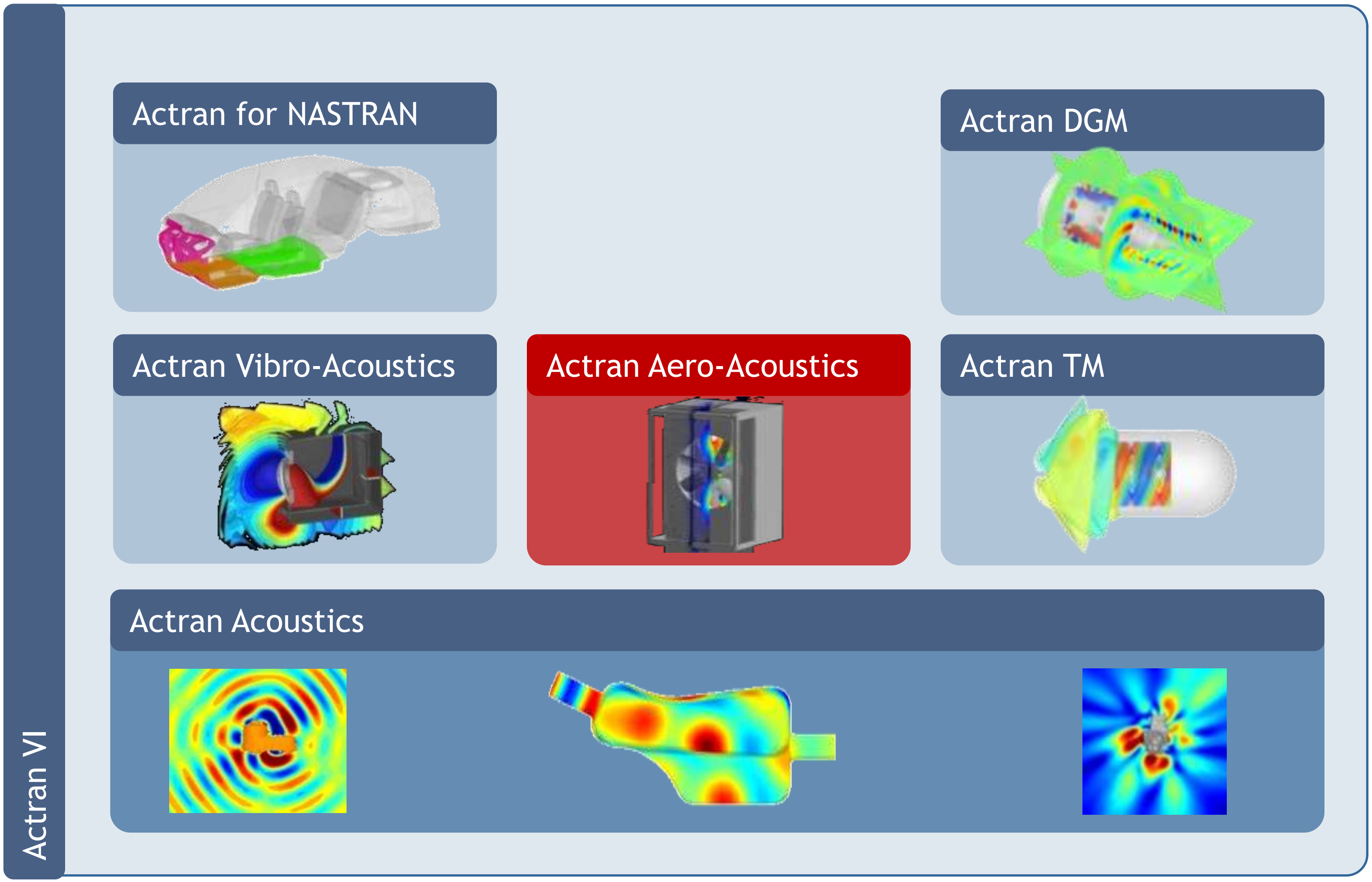
Pressure at 4000Hz



Pressure at 500Hz



The Actran software suite



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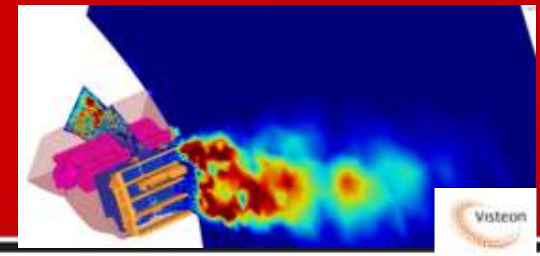
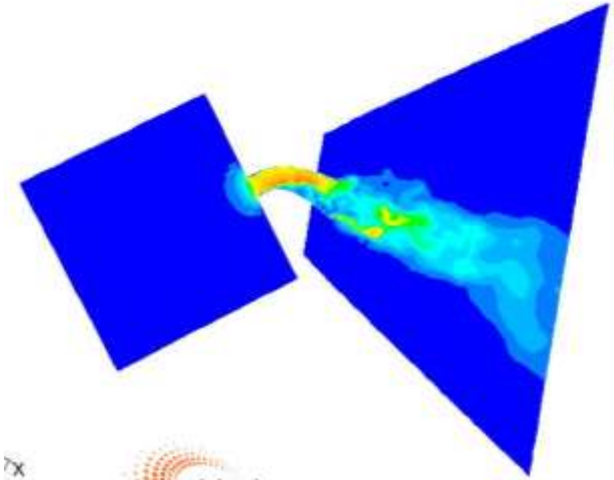
CAA

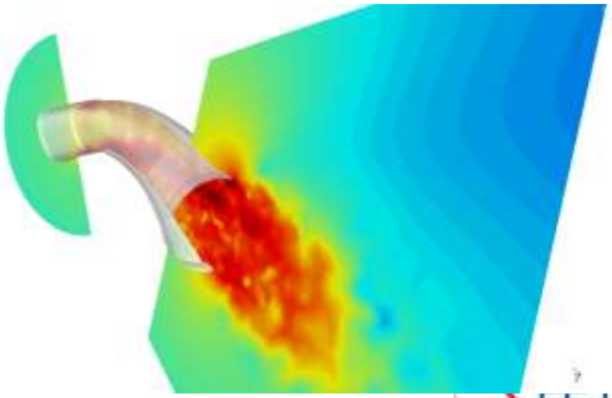


- **CAA means Computational Aero-Acoustics**
- **Several strategies**
  - Direct computation: the unsteady CFD solution also contains the acoustic results
  - Hybrid method: the CFD produces intermediate results used afterwards in an acoustic computation
  - Semi-empirical models, not relying on unsteady CFD
- **In theory the direct solution using CFD seems attractive but in practice it is not**
  - The CPU requirements are hardly affordable (due to CFL criterion and model size)
  - CFD schemes need numerical dissipation to stabilize the solution ➔ kills the acoustic wave
  - energy of turbulence >> acoustic energy → difficult to extract the acoustic information
  - Difficult to set-up a non-reflecting condition, to introduce acoustic treatment or to couple with a vibrating structure
- **Solution ? Hybrid method !**

Hybrid Method : Actran

- **Two decoupled steps**
  - Step 1: compute the unsteady flow using CFD
  - Step 2: extract sources from the CFD results and propagate
- **Assumptions in principle**
  - Main assumption: no interaction between the vortical and acoustic modes
  - In clear words: the acoustic field does not modify the flow
- **Challenges**
  - Find the “good” wave operator
  - Find the “good” source terms
  - Extract these source terms accurately from CFD input





Lighthill's Analogy: General idea

- Start from the equations of the Fluid Dynamics (Navier-Stokes)
- Make as few assumptions as possible
- Manipulate the equations to "form" a wave equation of this form

$$\frac{\partial^2 \rho_a}{\partial t^2} - a_0^2 \frac{\partial^2 \rho_a}{\partial x_i \partial x_i} = \{\text{Source Terms}\}$$

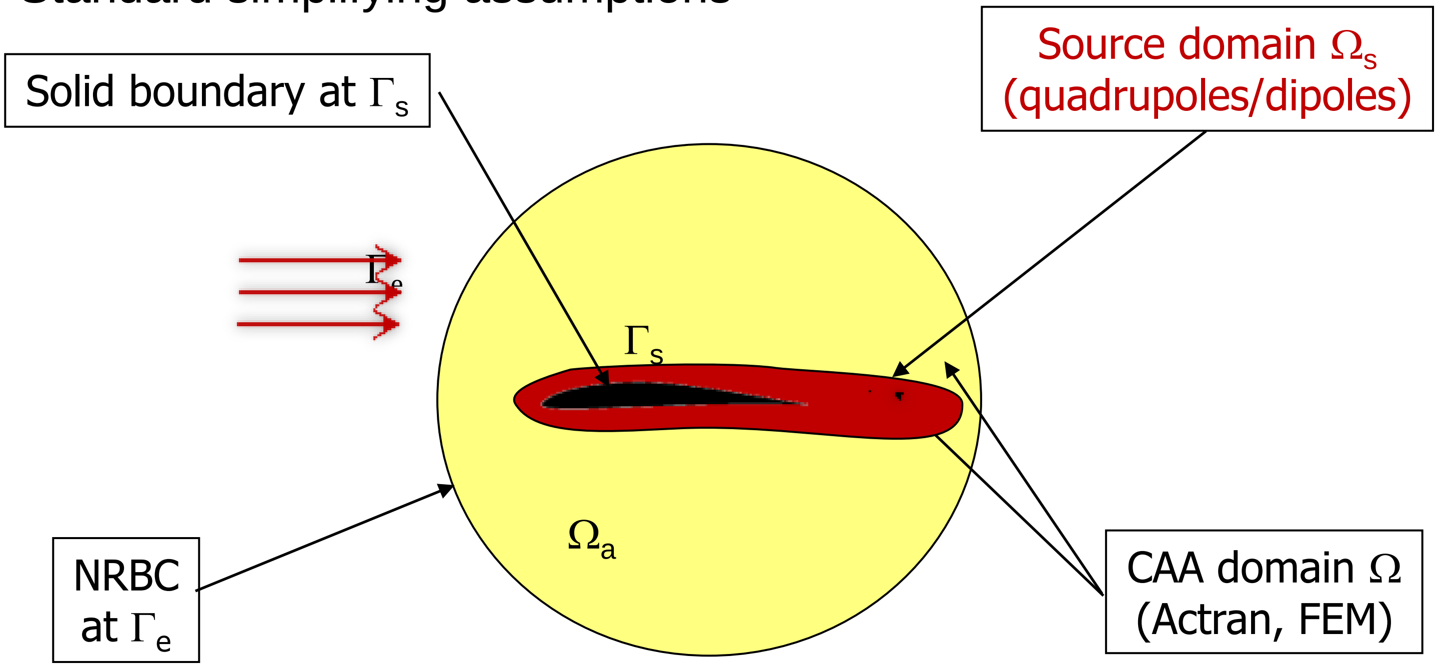
Where ρ_a is the acoustic variable

and the source term depends on ρ,u,v,w,p

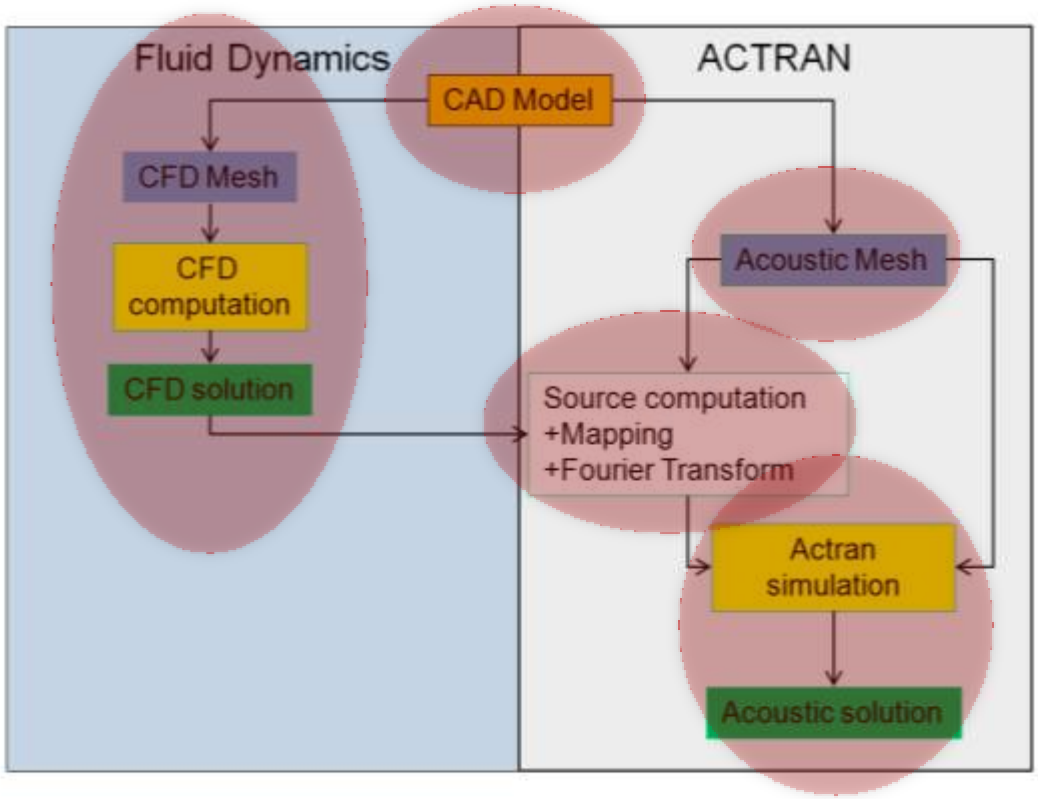
- Compatible with any kind of boundary condition = major difference with less powerful implementations (Curle, FWH or BEM)
- Limited to low Mach numbers but can be extended using the Mohring Analogy also implemented in Actran

Lighthill's Analogy: Sketch

- **An unsteady CFD computation (URANS, LES, DNS, …) is used to determine the flow**
- **The sound sources are calculated from these results**
  - Use of Lighthill's analogy
  - Standard simplifying assumptions



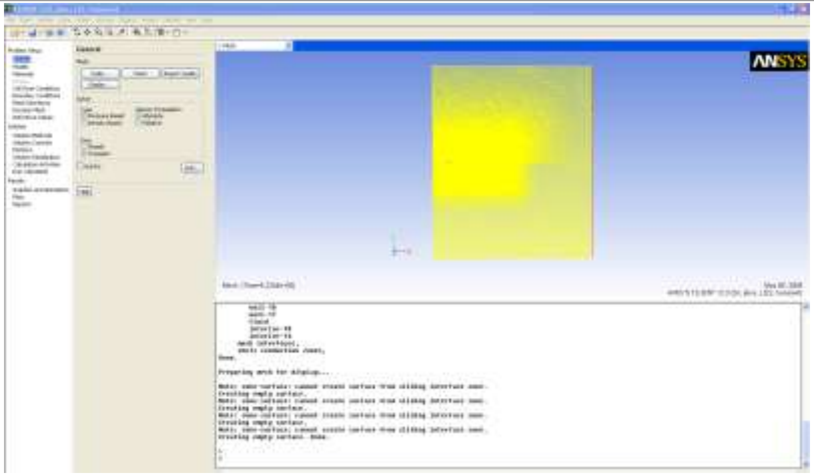
Process Overview

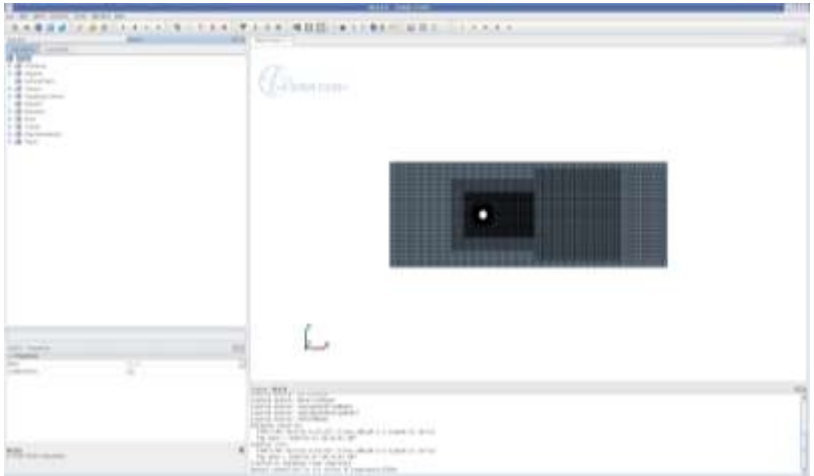


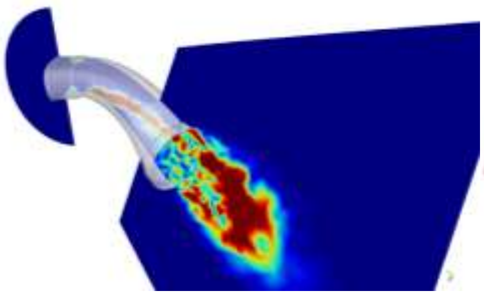
- **Easy to use procedure - CFD and acoustic computational chains are decoupled**
- **Efficient procedure - mapping strategy (integration technique). A pure acoustic meshing criterion is sufficient: there is no need for a refinement of the mesh in the sources zone**
- **Robust procedure Actran directly reads native CFD files**

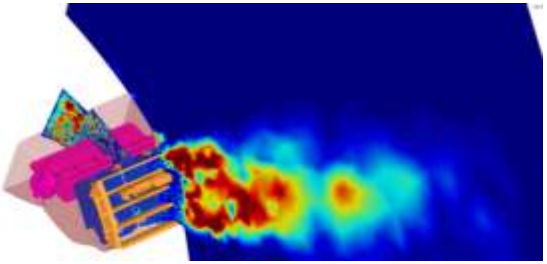
Interface with CFD Solvers

- **The coupling is operational for most standard CFD solvers**
  - Star-CD (native)
  - Star-CCM+ (native)
  - Fluent (native)
  - CFX
  - Powerflow
  - AcuSolve
  - Numeca Fine Turbo (native)
  - OpenFOAM (native ongoing)
  - …



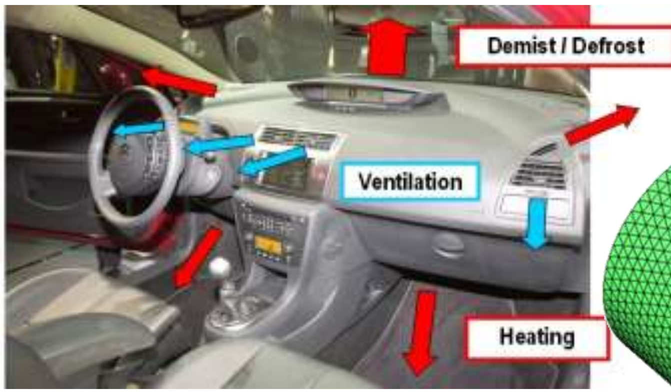


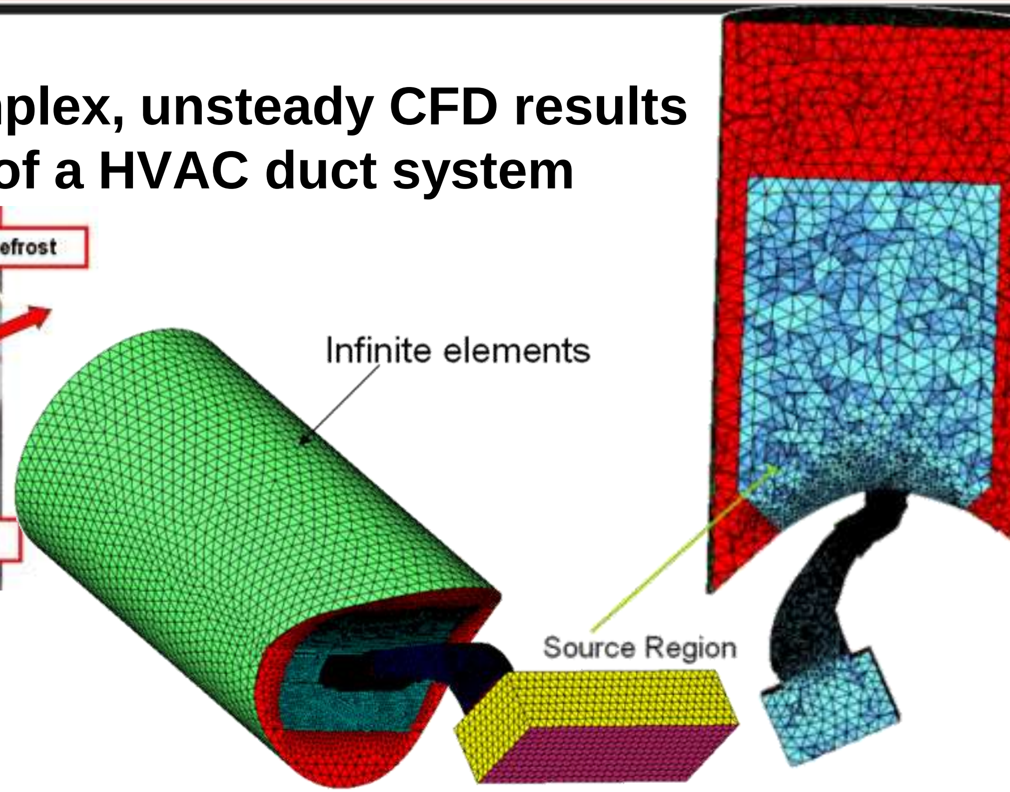




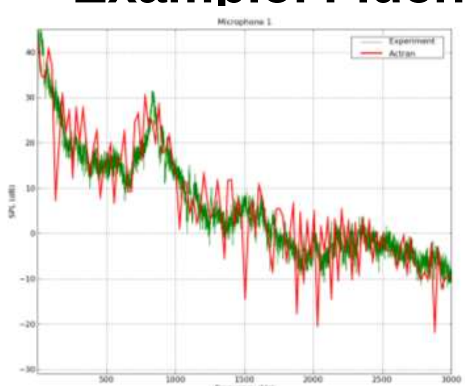
Application Review - Instrument Panel Duct

- **Objective: post-process complex, unsteady CFD results and compute the flow noise of a HVAC duct system**

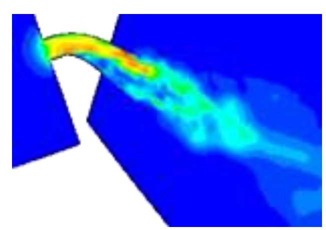


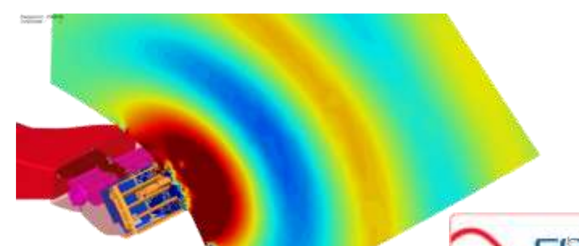


- **Example: Fluent + Actran**



ACTRAN TEST





- **Our unique strategy ensures excellent results**

Case studies Review

Study of the Noise radiated by an Intake Manifold

Hiroyuki Abe – MAZDA

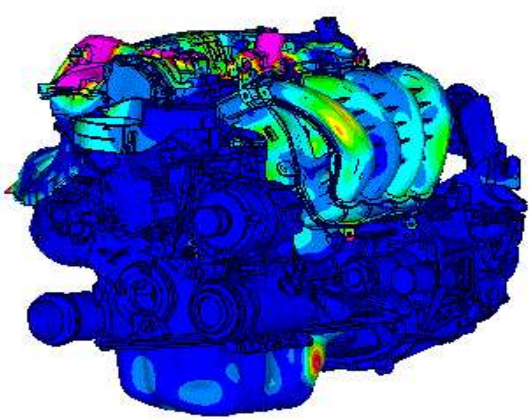
Work presented at the Actran 2011 User's Meeting in Japan

mazda

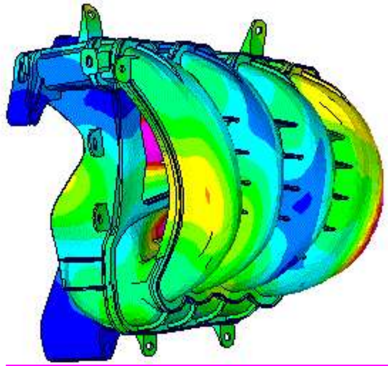
Introduction

- **Mazda has developed a new engine in order to reduce the fuel consumption as well as the weight (among others)**
- **To achieve this, Mazda decided to use a thin resin intake manifold**
- **Consequence: many modes are present because of the low rigidity of the intake manifold and therefore some significant noise problem occured**
- **Mazda has to consider many structural modifications in order to fix this problem**

Computational Process

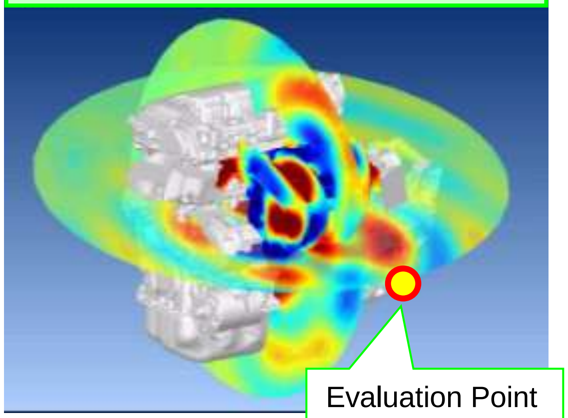


PT Vibration - NASTRAN



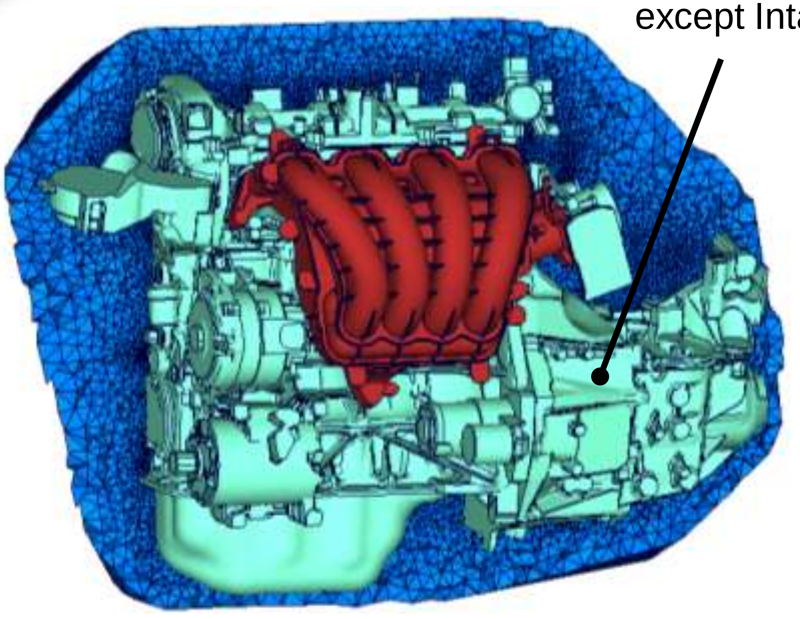
Intake Vibrations

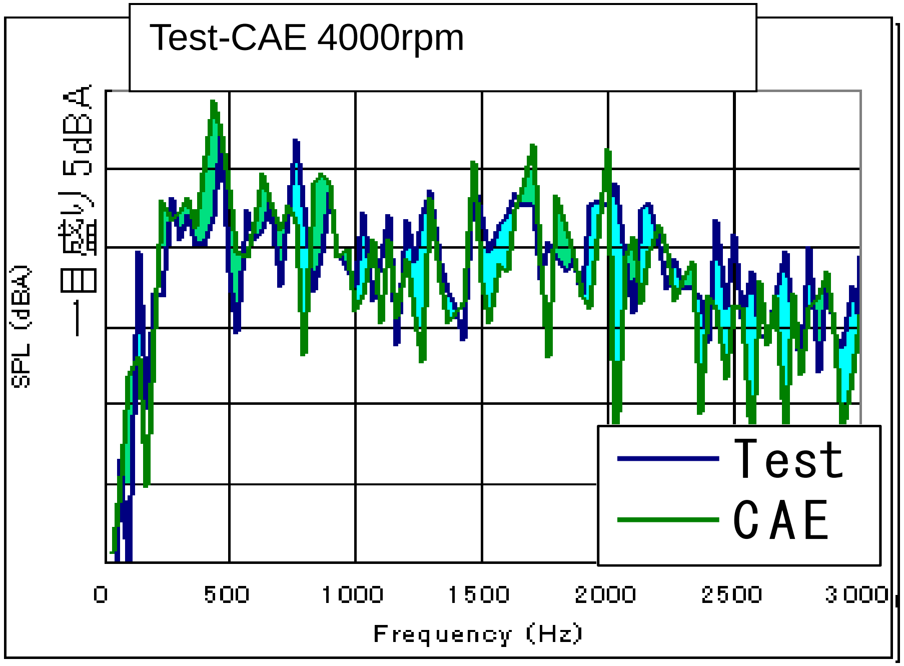
Acoustic



Results

Rigid Parts
except Intake

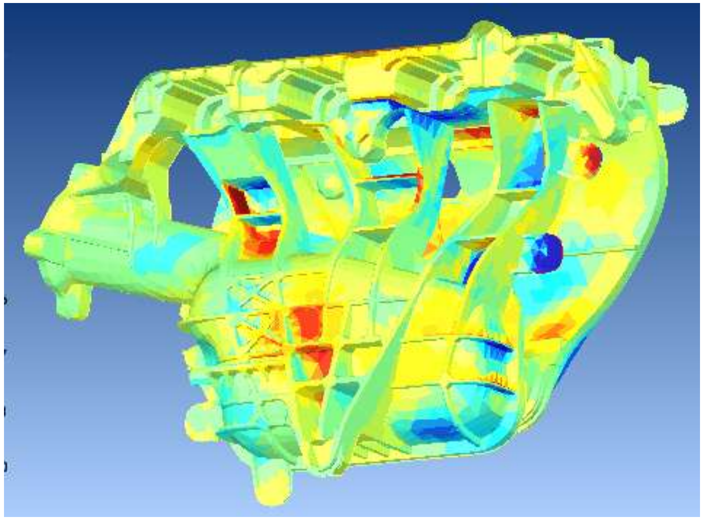




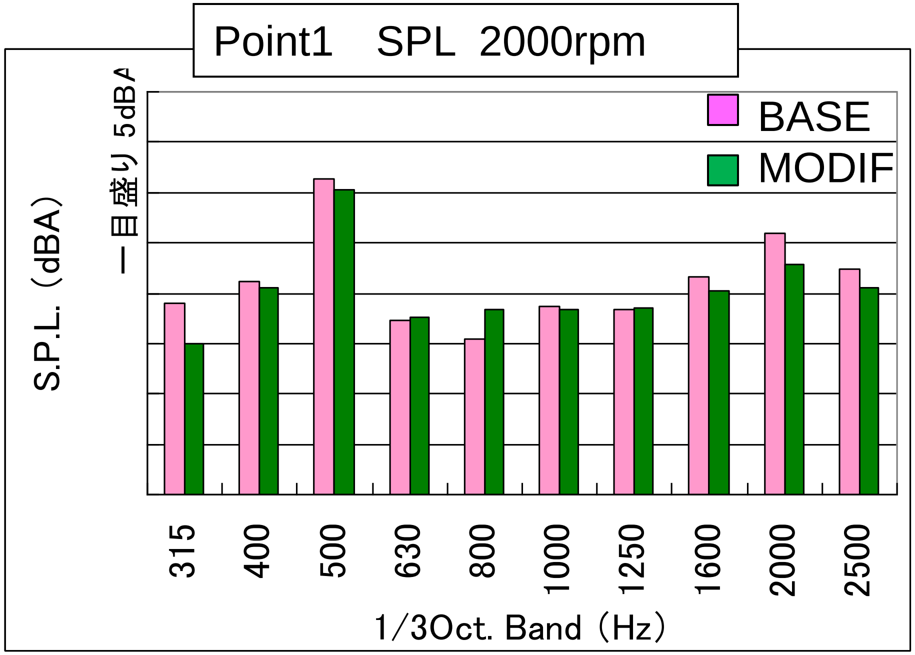
- **Correlations are very good!**

Design Improvement

- **Thanks to the accuracy and to the performance of Actran, Mazda can use the numerical simulation to improve the acoustic performance of its engines**



Element Contribution

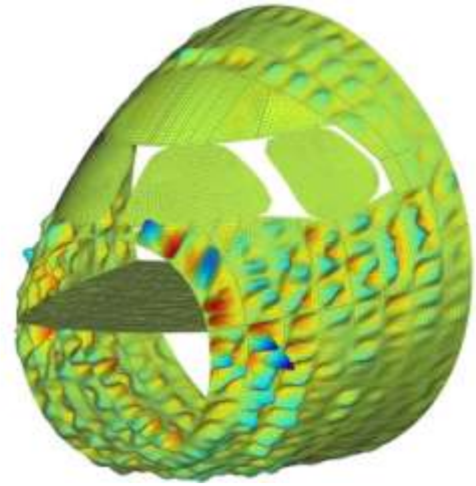


- **The weight has been reduced as well as the noise (4dB at the maximum)**

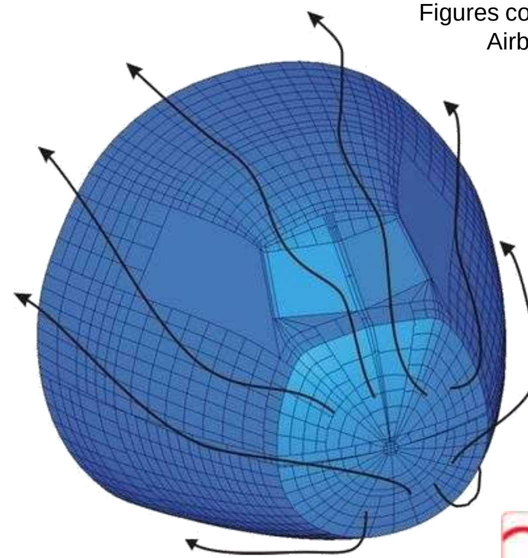
Other Application Reviews

Application Review : Noise Transmission through Fuselage & Cockpit – Models

- **FE Actran models take into account**
- **Real shape & structural heterogeneity effect**
  - Upper cavity (5 m3)
  - Insulation (Glass wool)
  - Multi-layered windows
  - Composite Fuselage
  - Stringers and Frames
- **Excitation type effect**
  - Diffuse sound field
  - Turbulent boundary layer (Corcos)
  - Engine structure borne vibration levels
  - User defined (e.g. propeller noise)

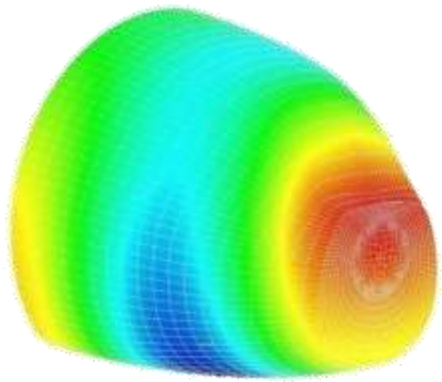


Figures courtesy of Airbus

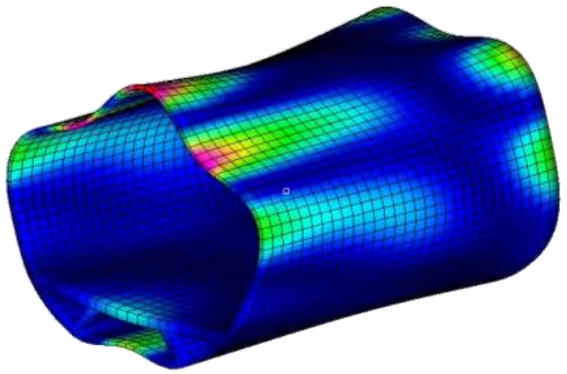


Application Review : Noise Transmission through Fuselage & Cockpit – Typical results

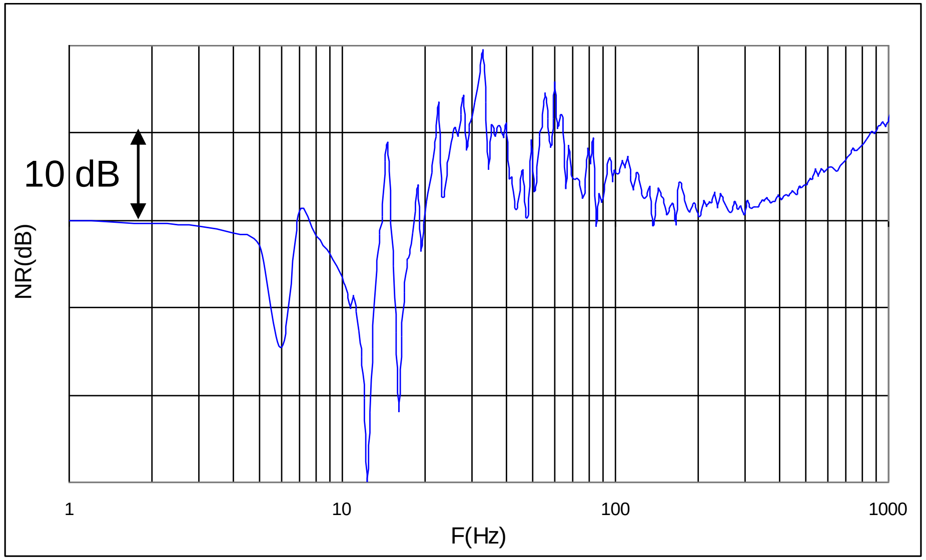
Cockpit interior SPL

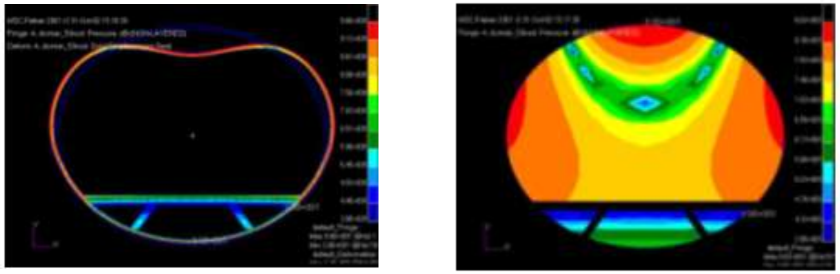


Cabin structure response



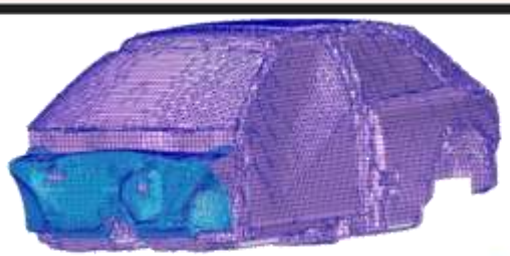
Cockpit sound transmission – NR Index



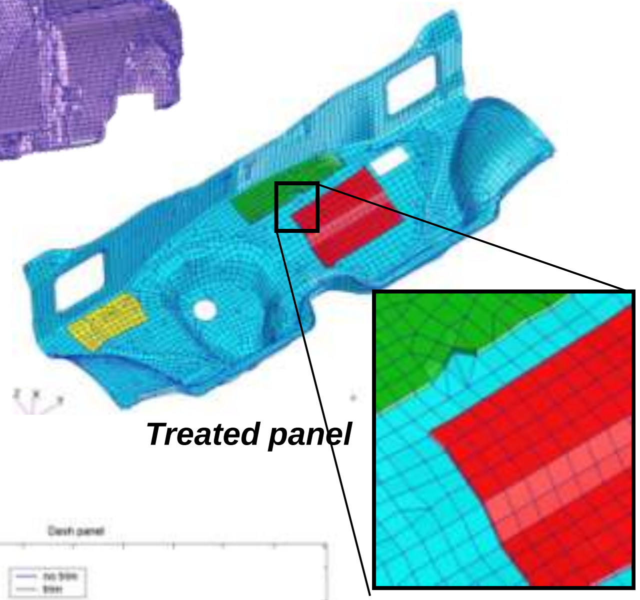


Application Review : Transmission through a dashboard & Treatment

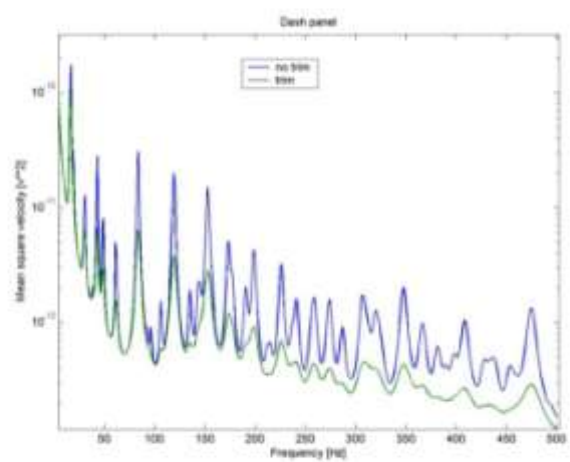
- **Key ingredients**
  - **Dashboard**: steel material & shells elements
  - **Treatment patches**: multilayer sandwiches made of foam (porous elements) + visco-elastic shells
  - **Acoustic cavity**: standard acoustic elements
- **Computational sequence = direct frequency response**
- **Typical outputs (FRF or maps)**
  - vibration levels
  - Sound pressure levels (SPL)
- **Influence of entire body can be accounted through a super-element import**



connection to the car cavity



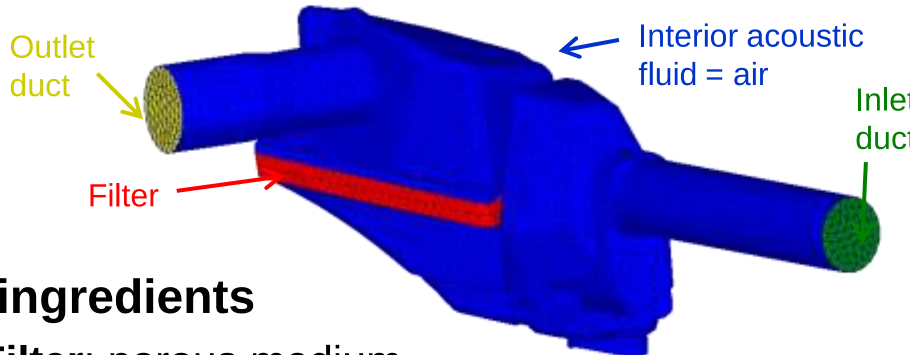
Treated panel



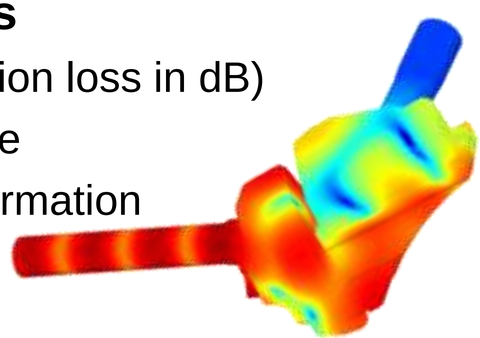
Dynamic response with and without acoustic treatment

Application Review : TL of an Air Filter

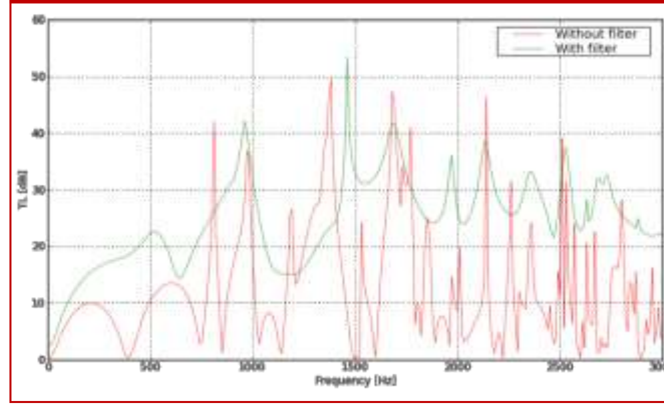
- **Objective : compute the transmission loss of an air filter**



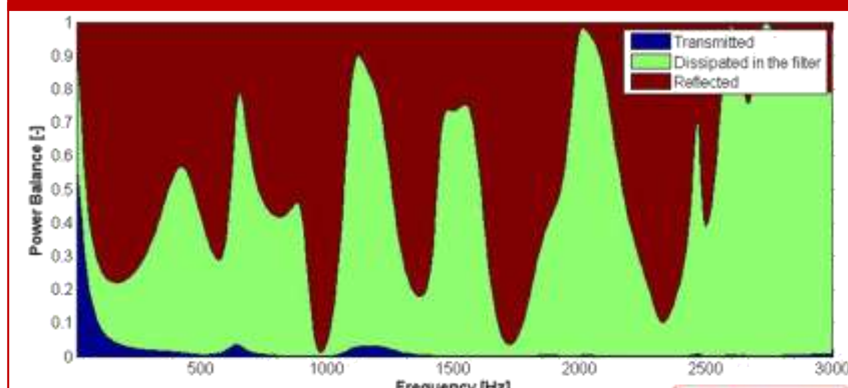
- **Key ingredients**
  - **Filter**: porous medium
  - **Structure in plastic**: shell elements
  - **Acoustic** finite elements for the air medium
  - Duct mode BC for **inlet and outlet pipes**
- **Typical Outputs**
  - TL (transmission loss in dB)
  - Power balance
  - structure deformation
  - SPL maps



Transmission Loss



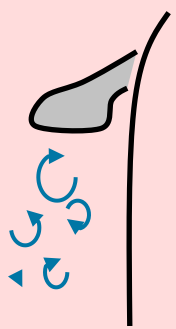
Power Balance



Application Review - Side-Mirror Noise 1/3

- **Two main phenomena occur, both are caused by the turbulence, the true noise is the sum of both**

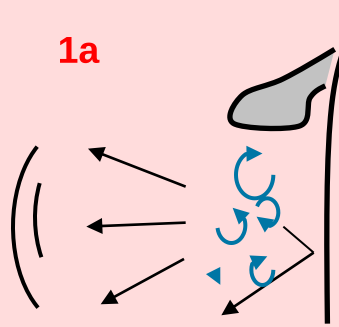
1. **The turbulence is, itself, a source of noise**
   - The vortex structures shed downstream the side mirror are sources of noise
   - The noise is influenced by the presence of the side window (AWPF) 1a
   - The noise is partially transmitted through the side window 1b



Turbulences **into** CFD solver

Vortex structures shed downstream the side mirror generates turbulences

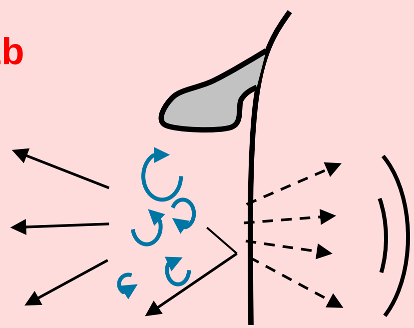
1a



Actran Aero-Acoustics

Turbulence noise (from the vortex structures) outside the car only

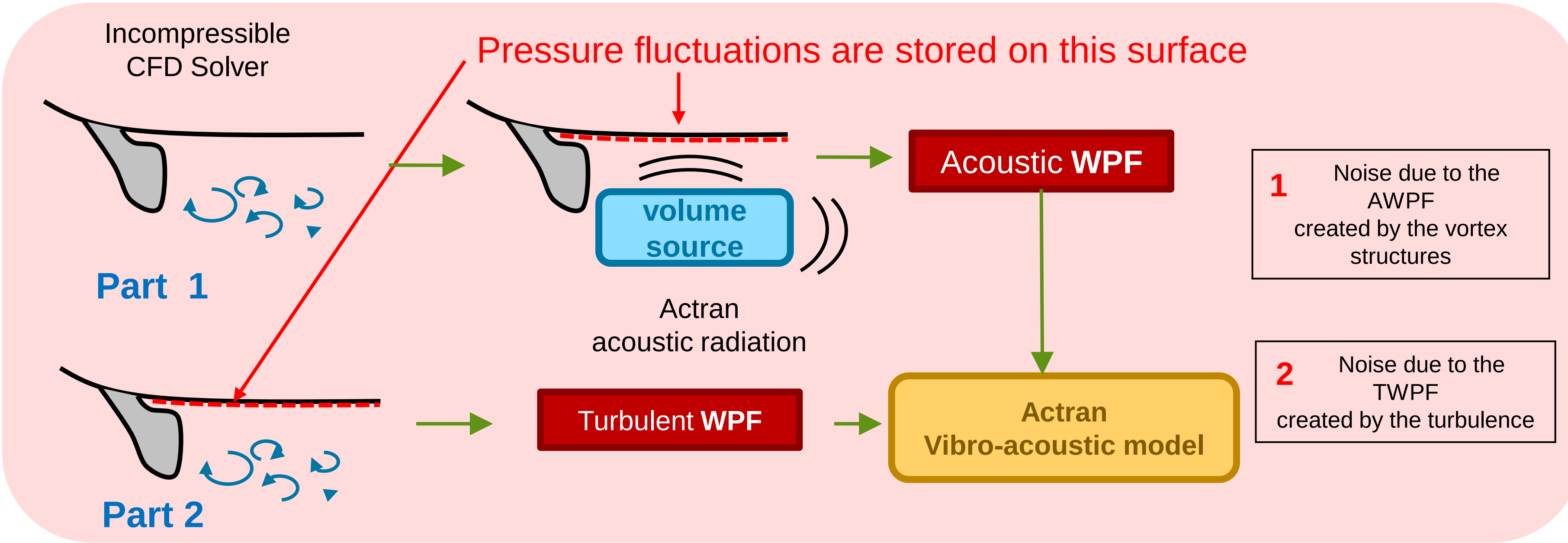
1b



Actran VibroAcoustics

Noise transmission through the window

Application Review - Side-Mirror Noise 2/3

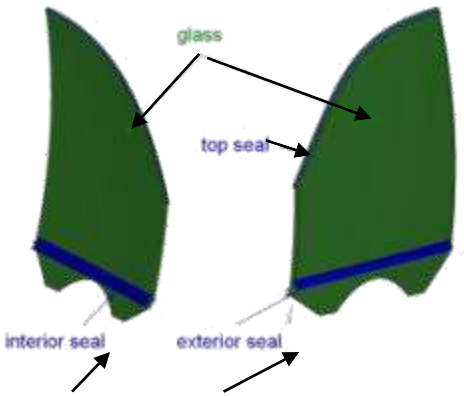


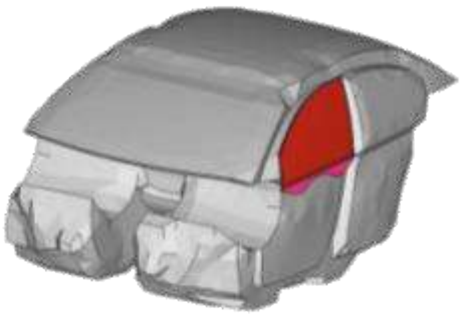
2. **The turbulence also induces a turbulent pressure fluctuation at the walls (TWPF)**
   – This TWPF causes a vibration of the visco-elastic structure of the side window

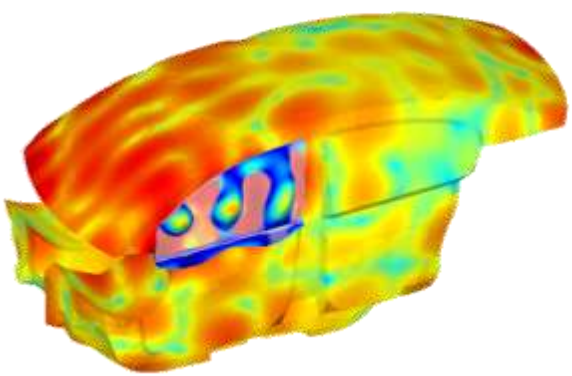
- **These two phenomena can be studied in Actran and involves two different modeling strategies**

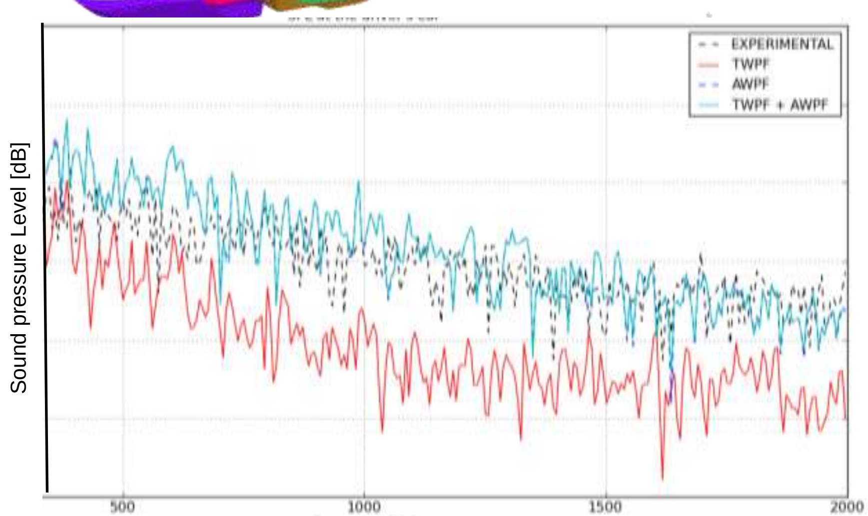
Application Review - Side-Mirror Noise 3/3

- **Volskswagen Passat**
- **Window = visco-elastic shell, seals = visco-elastic solids**
- **Trim components into the cavity using admittance**





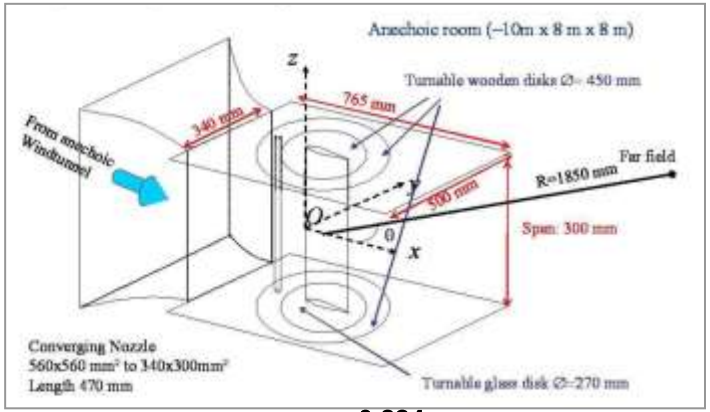


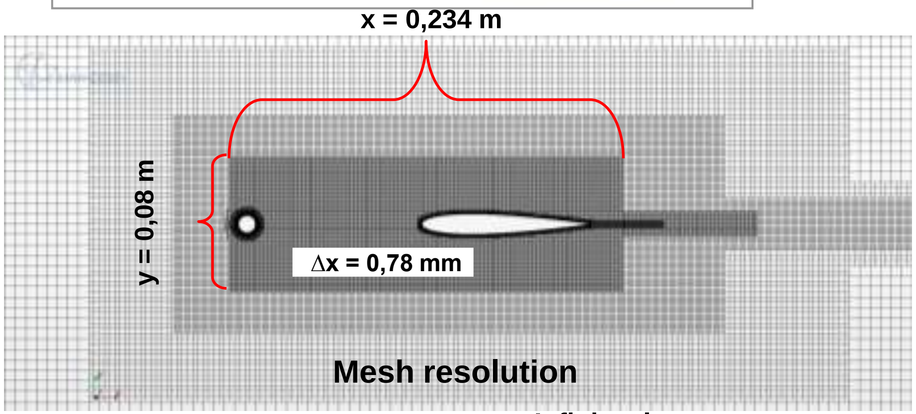


Case Study : Rod-Airfoil – Set-up

DAIMLER

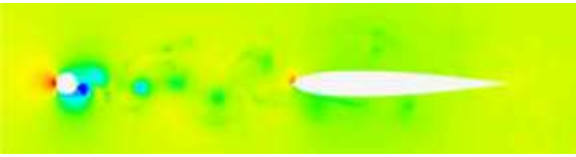
- **Experimental setup**
  - Cylinder: ø = 10 mm
  - Airfoil: NACA 0012,
  - c = 100 mm
  - Span: 300 mm
  - Far field measurements: R = 1.85 m
- **CFD Simulation Setup**
  - DES with StarCCM+ (V6.05)
  - Computational domain: 6 m x 4 m x **0.3 m** (x, y, z)
  - Step by step refinement until 0.78 mm in the finest region
  - Simulation time: T = 0.2s with $\Delta t = 1*10^{-5}$s
- **Acoustic Simulation Setup**
  - Mesh refinement : 17mm
  - On-the-fly mapping from CFD





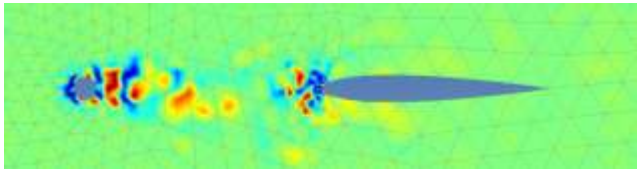
Mesh resolution

Source mapping



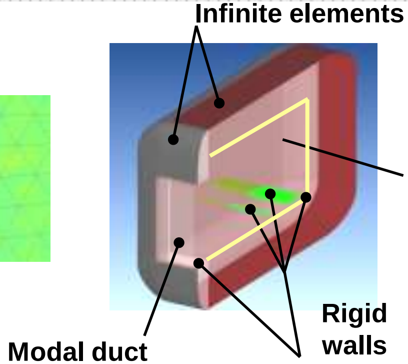
Unsteady CFD results

CFD mesh



Acoustic mesh

Acoustic sources



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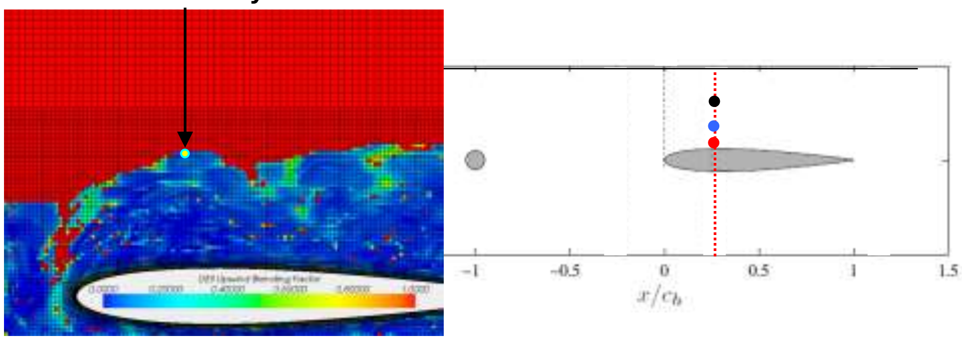
Case Study : Rod-Airfoil – Results

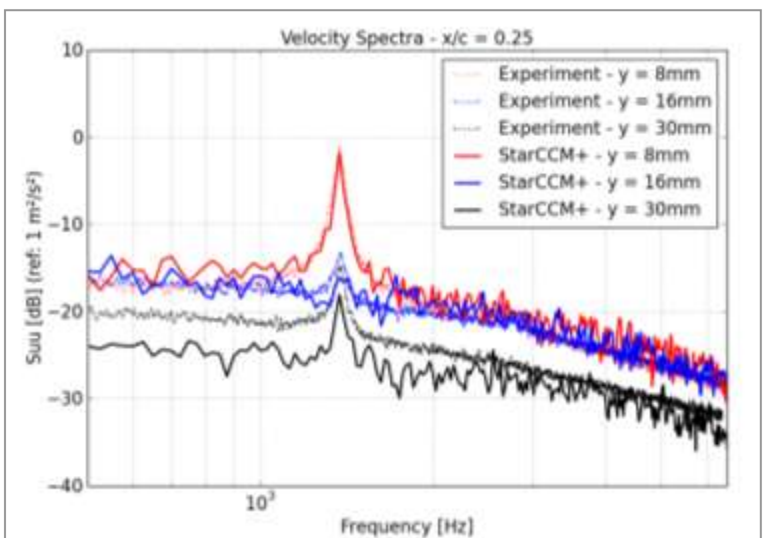
DAIMLER

Aerodynamics

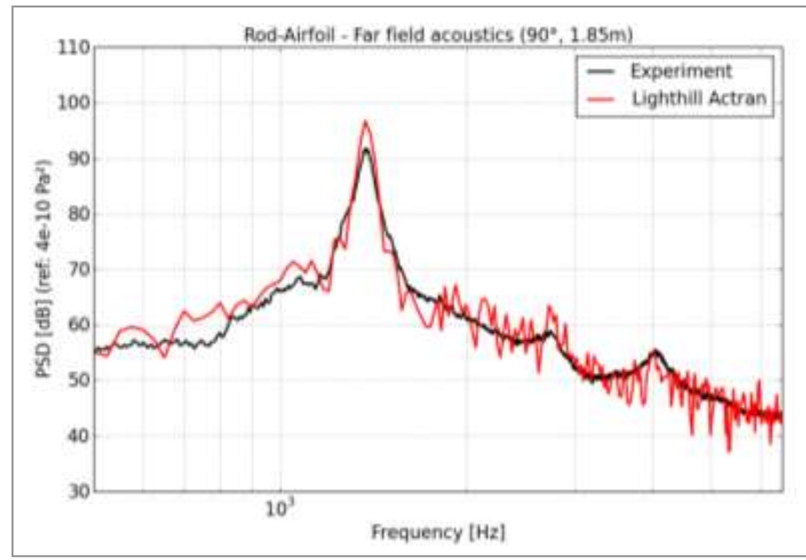
x = 25mm / y = 30mm



DES Upwind Blending Factor



Acoustics



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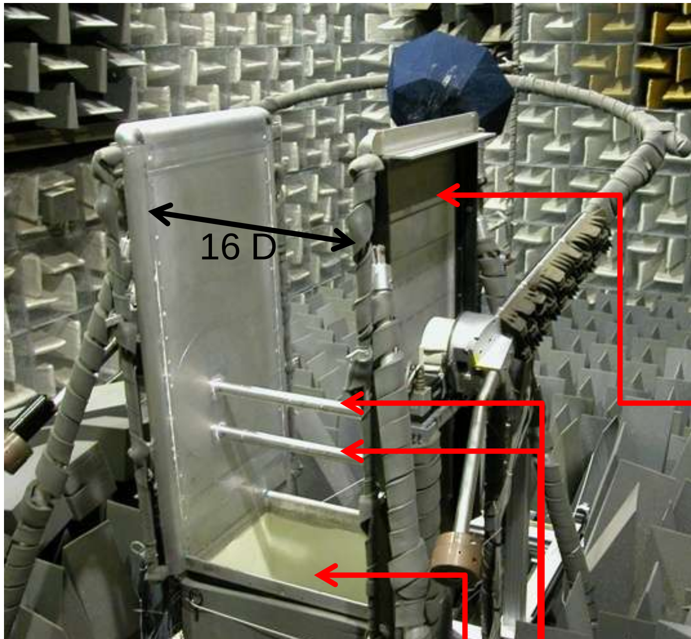
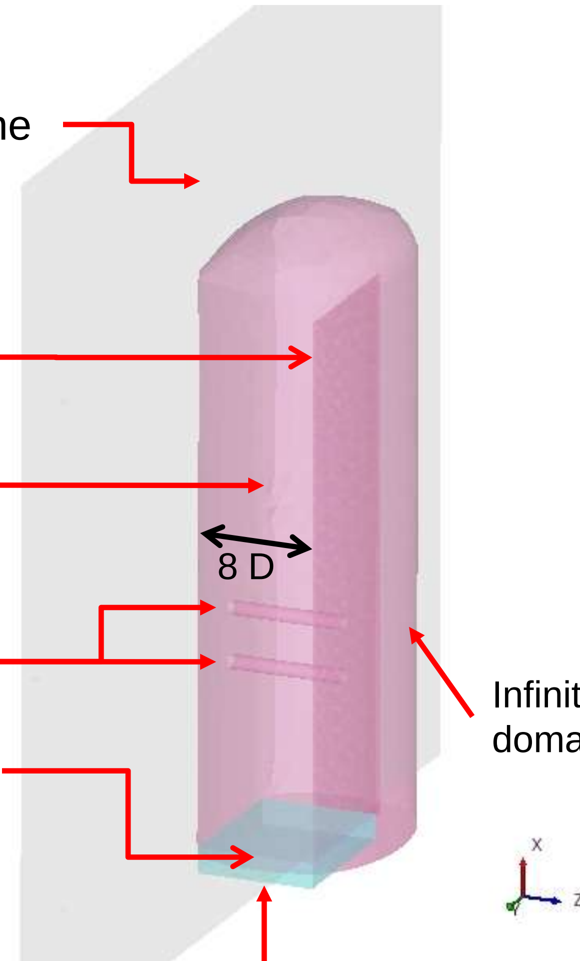
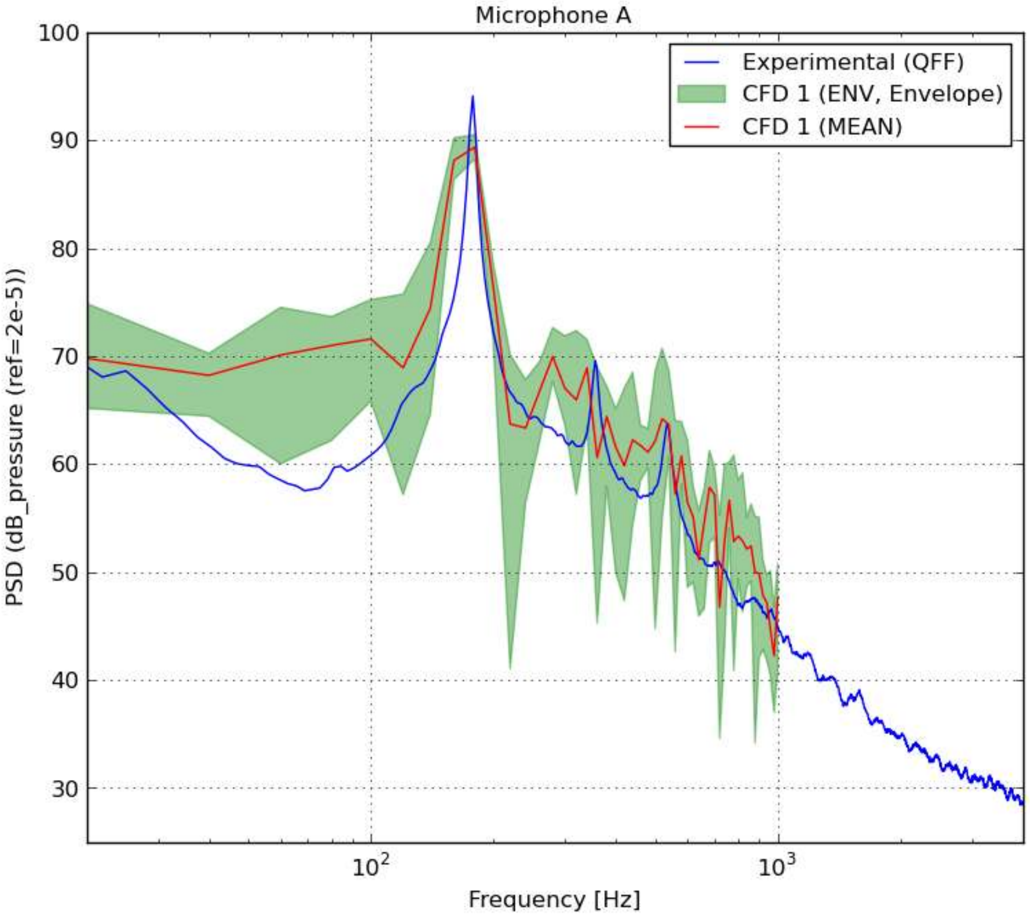
Application Review - Tandem Cylinders 1/2





Actran setup fully reproduces experimental NASA QFF conditions
More details on the BANC Tandem Cylinder benchmark available here
https://info.aiaa.org/tac/ASG/FDTC/DG/BECAN_files_/Workshop_June_2010_Final_Problem_Statements

Application Review - Tandem Cylinders 2/2

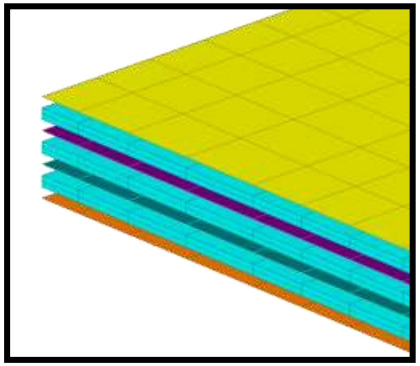


Application Review - ATV Solar Array Study Objectives

- **At lift-off, components like satellites carried on launchers are exposed to intense acoustic excitation that can damage their structures**

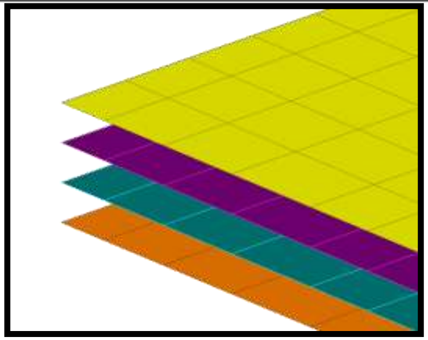
- **In the frame of an ESA driven project, Dutch Space is seeking for improving the prediction of the response of a folded solar array loaded by an Acoustic Diffuse Field**

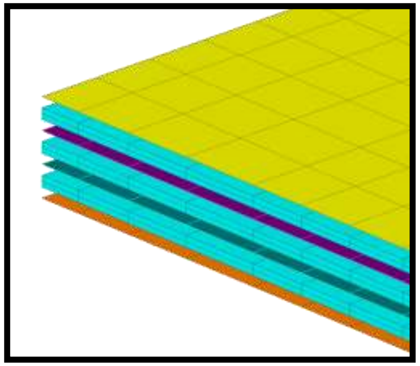
- **The objective of the study is to compare the vibro-acoustic response of a folded solar array loaded by an Acoustic Diffuse Field :**
  - Measured in a reverberant chamber (Dutch Space)
  - Simulated with the Infinite/Finite Element solver Actran (Free Field Technologies)

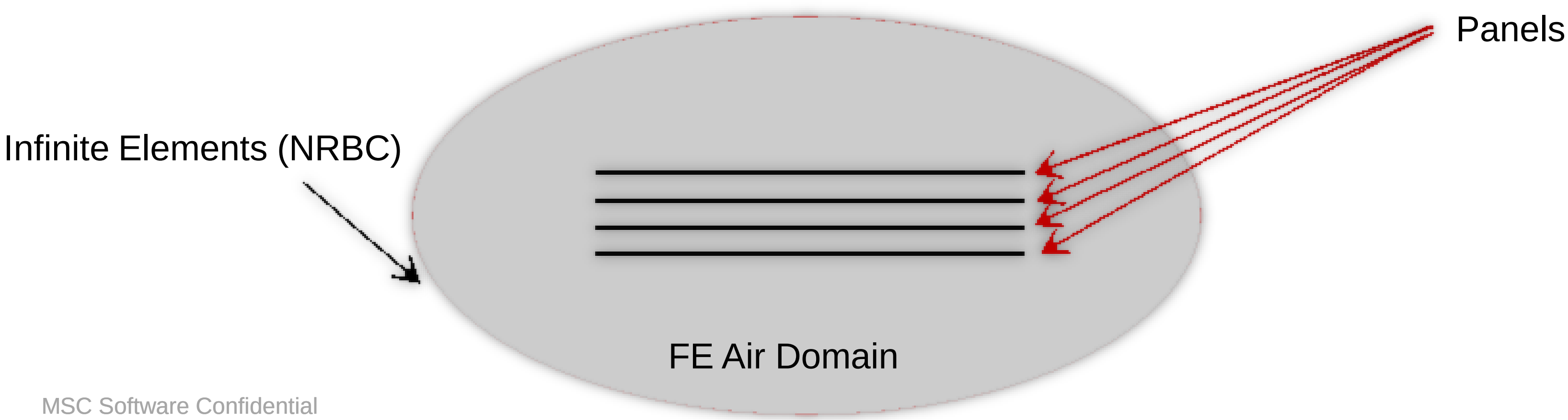


Application Review - ATV Solar Array Numerical Model

- **Structure modeled in modal coordinates**
  - Existing Dutch Space model
  - Modes extracted with NASTRAN (SOL103)
- **The air layers and the surrounding air are modeled together in <u>physical</u> coordinates**
  - Meshed with the real thickness
  - Take visco-thermal effects into account (Beltman model)
- **Fluid / Structure coupling taken into account (between each panel and fluid layer)**

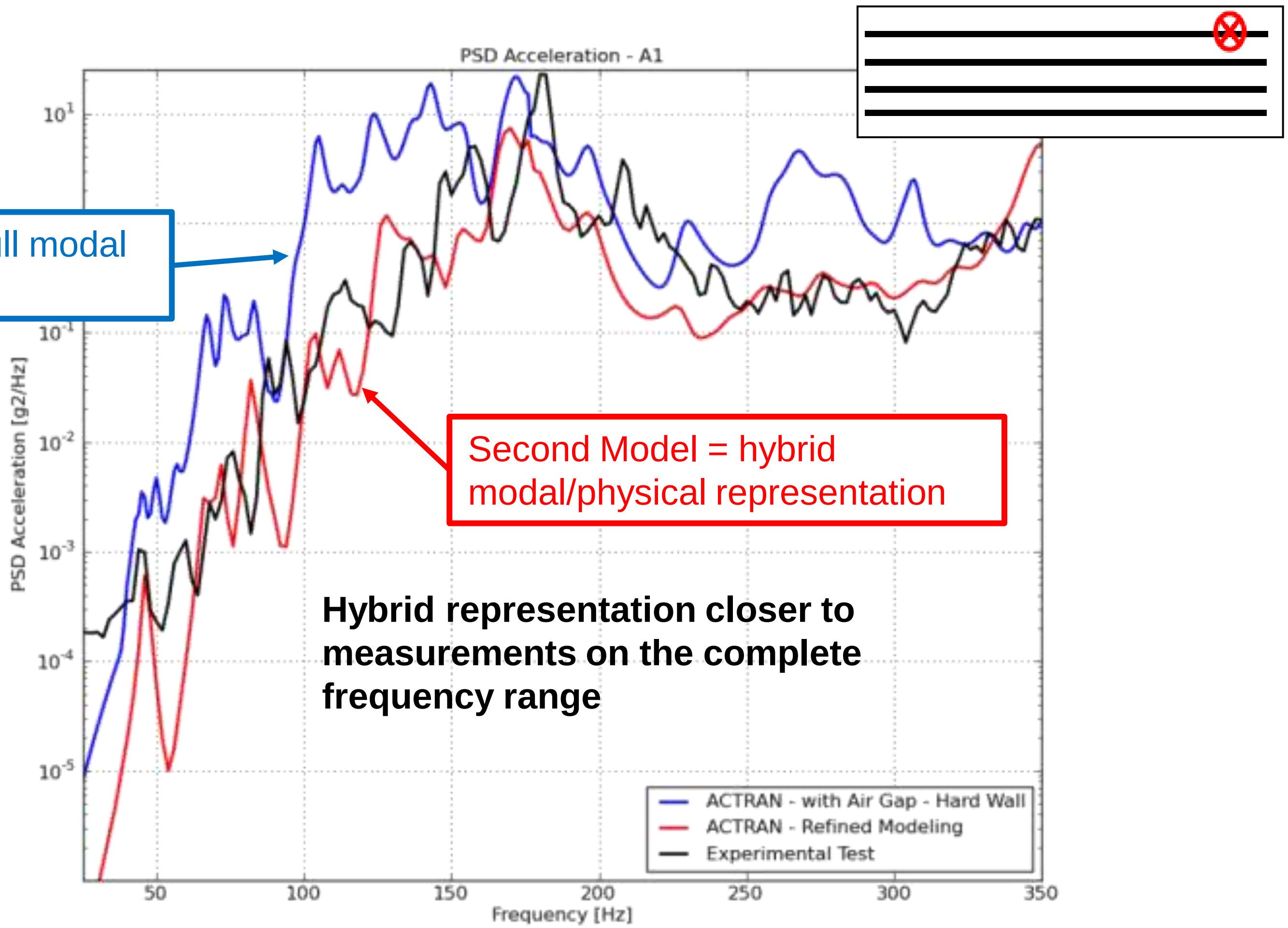






Application Review - ATV Solar Array Results

- **Influence of the air layers and Acoustic Diffuse Field models**



Full Model = full modal representation

Second Model = hybrid modal/physical representation

Hybrid representation closer to measurements on the complete frequency range

Actran can also be used for…

- **Turbofan engines**
- **Embarked structures within spacecrafts**
- **Trimmed body models for cars & trucks**
- **Electronics**
- **Loudspeakers**
- **Headsets, telephones, microphones,**
- **Underwater acoustics**
- **Shipbuilding**
- **Compressors**
- **Construction**
  - Glass structures
  - Multi-layered construction panels
- **Etc**
- **Contact us if you need more information !!**

Acoustic Services

- **Acoustic Engineering Services are offered from**
  - FFT's offices in Belgium, France, Japan & USA
  - Or through any local MSC office
- **Several highly skilled staff with thorough acoustics and structural dynamics background**
- **Deep experience in numerical acoustics, vibro-acoustics and aero-acoustics consultancy projects for the automotive and aerospace industry such as intake and exhaust noise, NVH of trimmed body, engine noise radiation, HVAC noise, Side Mirror Noise, windows transparency, …**
- **Also skilled in using other CAE software and high-performance computing resources**
- **Please take a look to our dedicated leaflet**

Conclusions

- **Actran offers a complete numerical solution to perform efficient acoustic design study for all the industrial applications**
- **From acoustics to vibro-acoustics to aero-acoustic studies**
- **All the modules have intensively validated by our customers: many publications can be downloaded on our website (www.fft.be)**
- **Very efficient solvers combined to different types of parallelism in order to perform fast simulations**
- **Actran can be directly plugged at the end of your structural or CFD analysis**
- **MSC & FFT teams also provide engineering acoustic services, on-site or off-site**