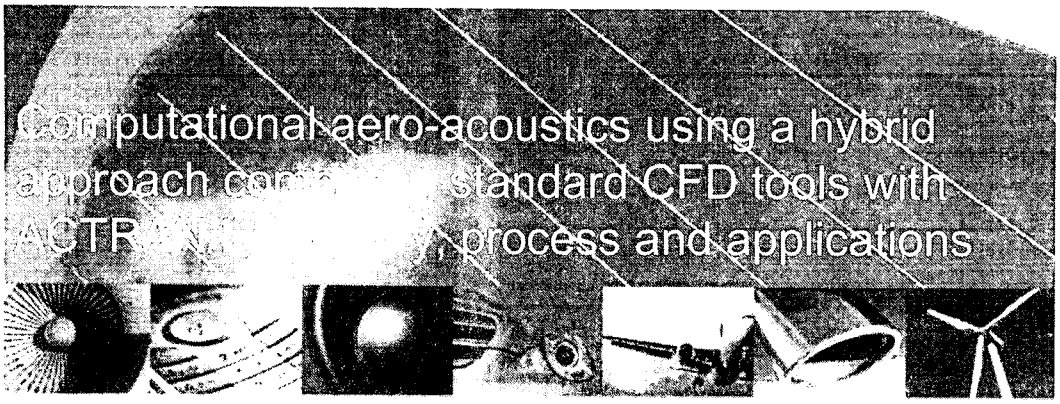
한국소음진동공학회 2008년 추계학술대회논문집, pp.545~560



Jean-Louis Migeot
Free Field Technologies

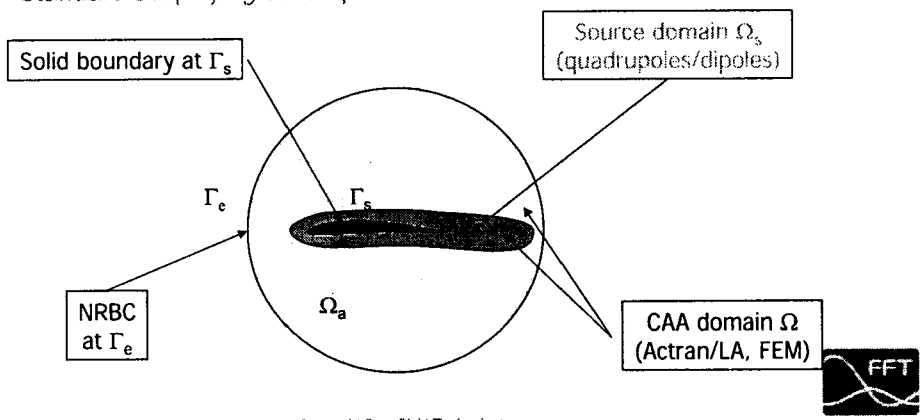
Presented to the Korean NVH Conference, November 2008

Outline

- Formulation used in Actran LA
  - Governing equations
  - Lighthill's analogy and comparison with integral methods
  - Implementation in Actran
- Exterior and interior problems
  - Flat plate using Fluent
  - Helmholtz resonator in a duct using Star-CD
  - Double diaphragm using Star-CD
- Porous boundary condition
- Conclusions

Lighthill's Analogy: Sketch

- A 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



Lighthill's Analogy: General idea

- Start from the equations of the Fluid Dynamics
- 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

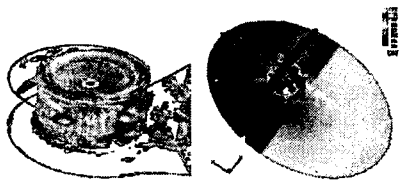
and the source term depends on ρ,u,v,w,p

- Put the Boundary Conditions of the Finite Elements
  - Any BC type can be used !!!
  - This is the main difference with the classical, less powerful implementations (Curle, FWH or BEM)

Actran/LA Computational Sequence

CFD Code
Turbulent CFD simulations

Primary Variables
Pressure, Velocity, Density, etc...



From CFD results to Acoustic results...

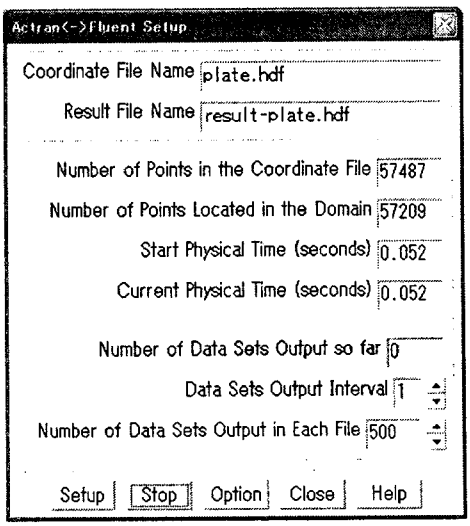
iCFD
-Transform CFD primary variables into acoustic sources
- Integrate these acoustic sources on the acoustic mesh
- Perform a Fourier transform

Actran/LA
- Propagate the acoustic sources computed by iCFD
- Output maps of the acoustic field and pressure at pre-defined positions

Actran/VI
Post-processing tool for Actran results

Coupling with CFD codes

- The coupling is operational for most standard CFD codes
  - Star-CD
  - Star-CCM+
  - Fluent
  - CFX
  - Powerflow
  - AcuSolve
  - OpenFOAM
  - ...



Example: Fluent's GUI

Some Actran/LA Customers

TRANE

CENAERO

AIRBUS

DELPHI

Visteon

Mercedes-Benz

PEUGEOT

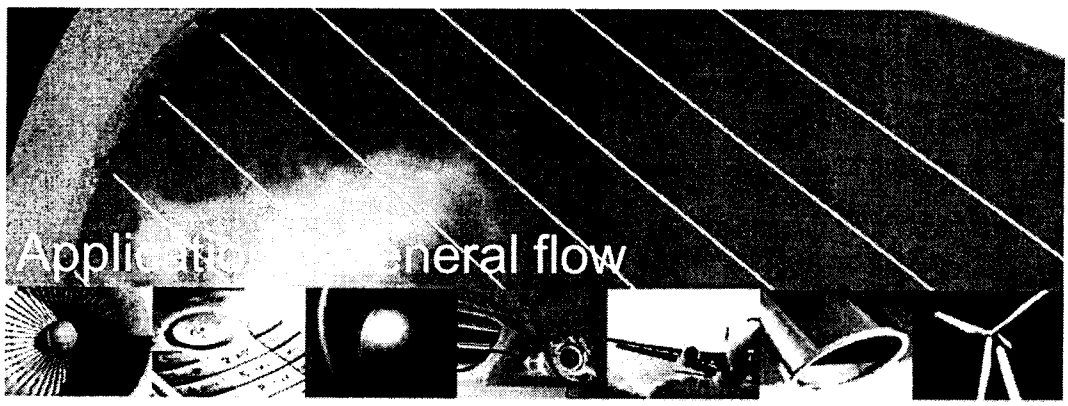
BMW

Nikon

JOHN DEERE

BEHR

FFT



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Helmholtz Resonator

AIAA05-3067: Aeroacoustic Simulation of the Noise radiated by an Helmholtz Resonator placed in a Duct - *S.Caro, P.Ploumhans, X.Gallez, F.Brotz, M.Schrumpf, A.Read, F.Mendonca*

CFD Results

Results

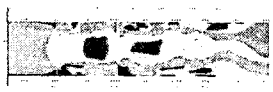
BEHR

FFT

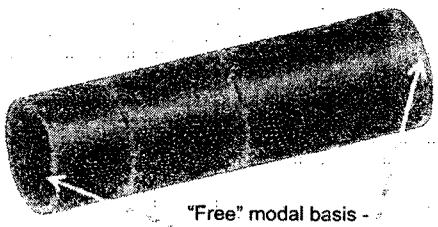
Double Diaphragm

AIAA05-2976: Aeroacoustic Simulation of Double Diaphragm Orifices in an Aircraft Climate Control System - *F.Mendonça, A.Read, S.Caro, K.Debatin, B.Caruelle*

CFD Results



Actran Model



"Free" modal basis - NRBC

Results

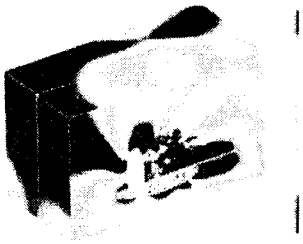
AIRBUS

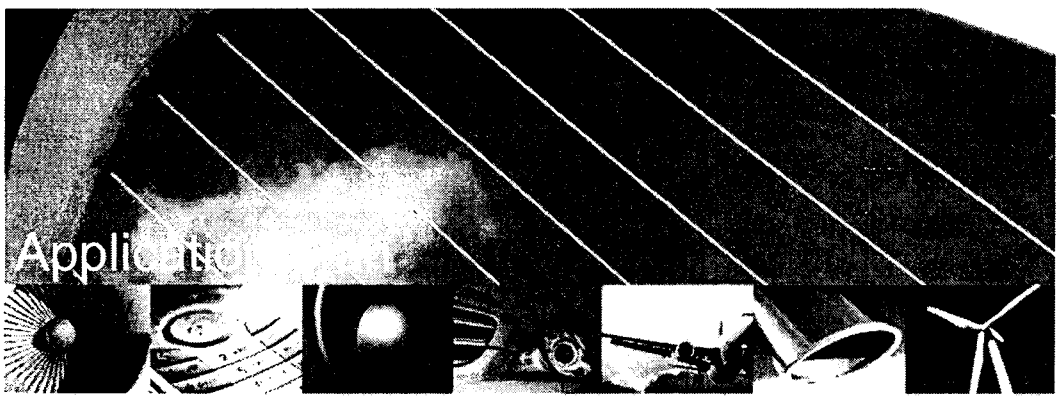
FFT

Applications with no experimental validation

Example – Simple Plate

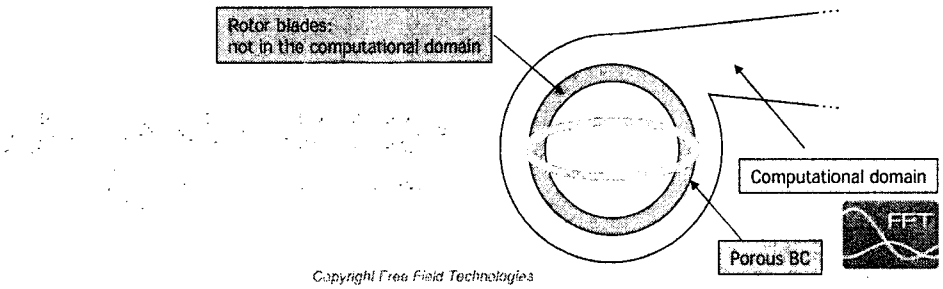
Example – Side Mirror





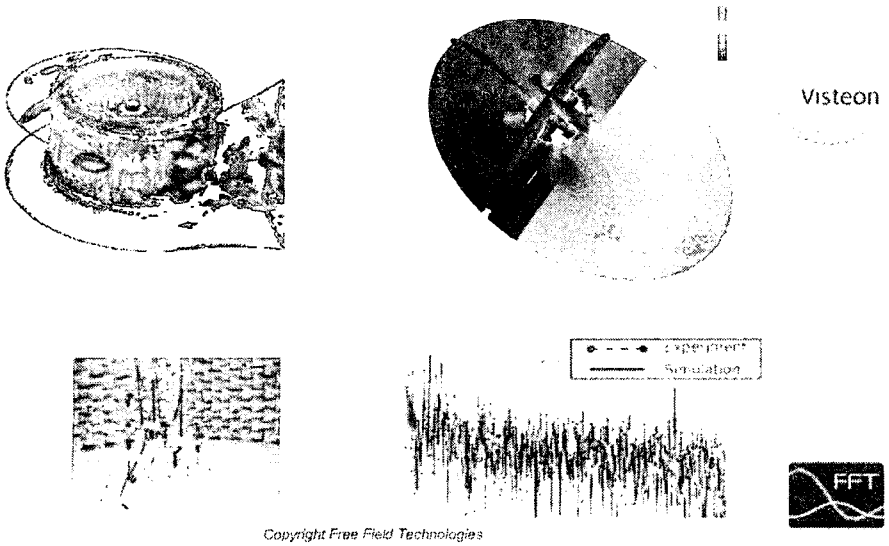
Main idea

- "Porous" Ffowcs-Williams and Hawkings idea applied to FEM
  - The sources outside the rotor zone will be accounted for "as usual" in Actran/LA
  - The sources in the rotor zone will be accounted for via a dedicated boundary condition
  - Start again from Lighthill's equations and put the boundary conditions
- Same idea as Kirchhoff theorem: the effects of the sources in the white area are accounted for through the orange boundary
  - Similarities in electromagnetism (Gauss theorem), optics...



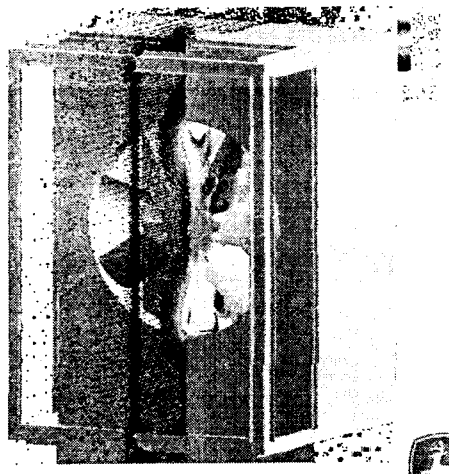
HVAC blower

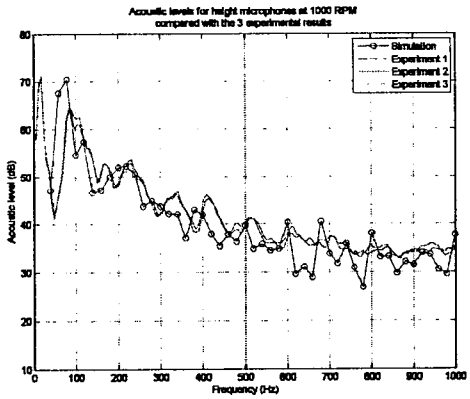
Fan Noise 2007: Presentation of a CAA formulation based on Lighthill's analogy for fan noise - *S. Caro, Y. Nishio, R.Sandboge, J. Iyer*



Axial EC fan

- Different heat exchanger types (weak influence)
- Several microphones everywhere; normalized test = average the results





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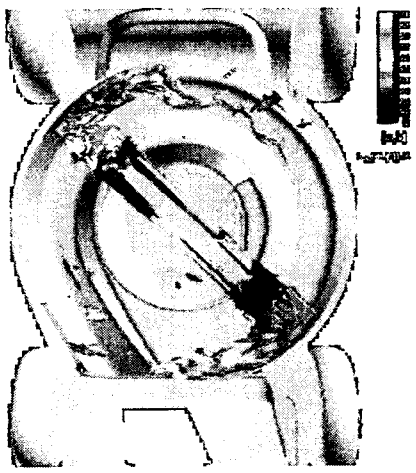
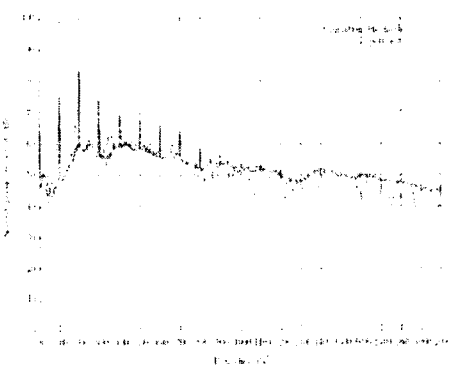
Mower application

- Lighthill Sources and Acoustic Field





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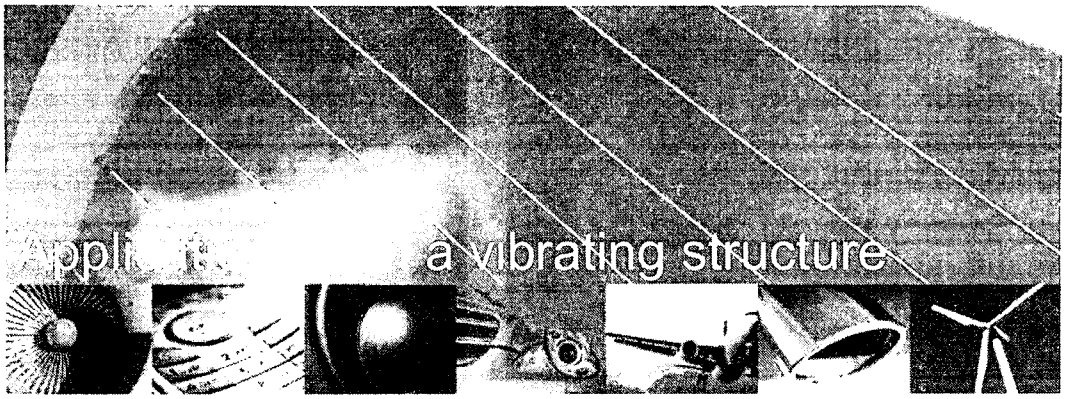
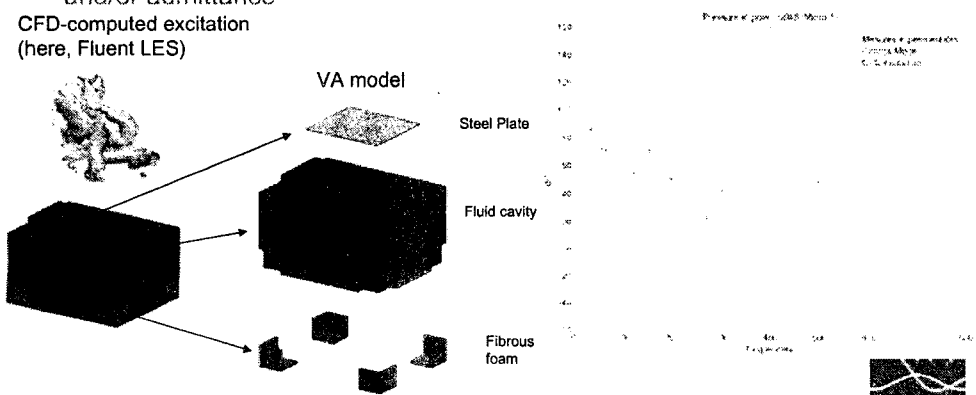


Side Mirror noise: Modeling strategy

- The formulation is FULLY COMPATIBLE with the vibro-acoustic features
  - A side window can be modeled by a visco-elastic shell
  - Its seal can be modeled by a visco-elastic material
  - The seats, carpets, dashboard etc can be modeled using the Biot model and/or admittance



Conclusions

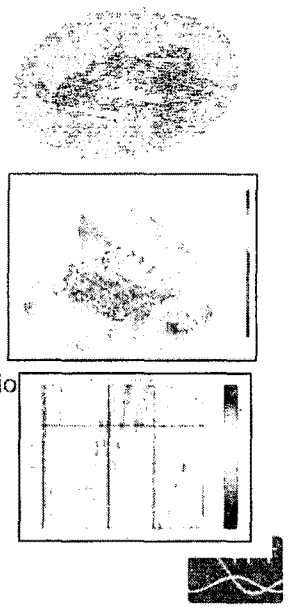
- Actran/LA formulation relies on a FEM-dedicated basis
  - The source formulation is much superior to the dipole/quadrupole formulations
  - The sources must be known with accuracy only where they are intense
  - The quality of the CFD does not need to be excellent
  - The method has been generalized to rotating machines
- Actran/LA is coupled to several CFD codes including the major ones; several "industrial-like" cases have been treated with some of them
- Actran/LA can be used for blower or axial fan applications
- Extension to Aero-Vibro-Acoustics is no problem
- Actran/LA has all the attributes of the other Actran family products

Jean-Louis Migeot
Free Field Technologies

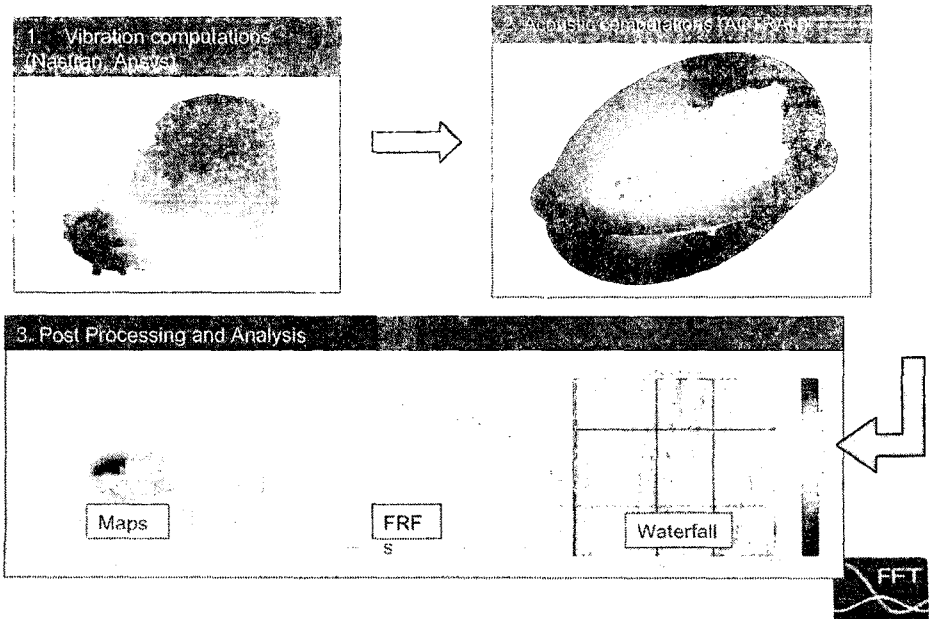
Presented to the Korean NVH Conference, November 2008

Actran for Exterior Acoustics

- Results provided (among other)
  - Acoustic pressure and power
  - Power distribution and radiation efficiency
- Realistic excitations
  - Vibration patterns from standard structural codes (NASTRAN, ANSYS)
- Ease of Mesh
  - Structural & acoustical meshes are unequal
- Fast Solvers
  - Direct and iterative solvers
  - Multiple Load solver (all regimes in a single computatio
  - Restart Capability
- Applications
  - Engine: power train and auxiliaries (oilpan, manifold, exhaust, ...)
  - Engine compartment insulation
  - Any vibrating / radiating Component



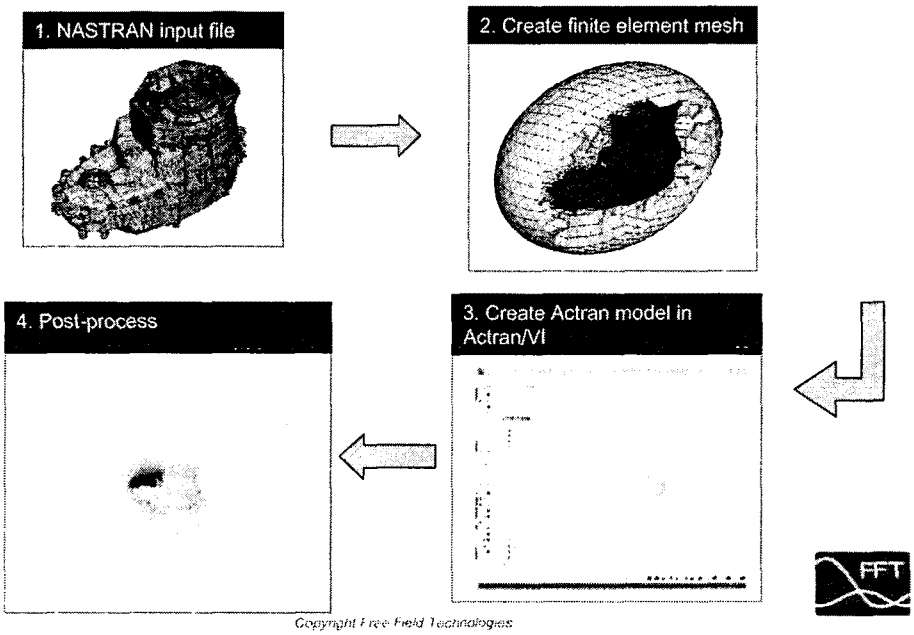
Standard Computation Process



Restart Capability

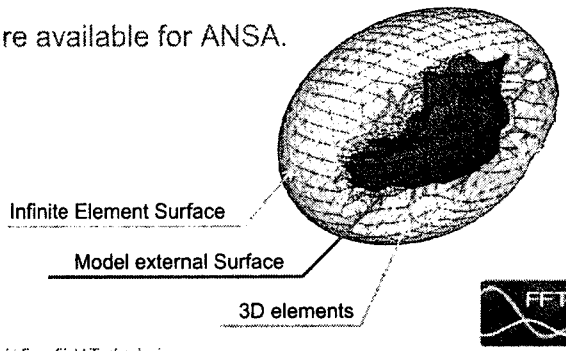
- New solver sequences allow the storage of the acoustic results before imposing the excitations. The application of the excitation can be done subsequently in a very short time.
- Thanks to this restart capability, the acoustic computation can be uncoupled from the structural computations. This eases the industrial process : if you modify the material properties or the excitation of your structural model, you do not have to re-do the acoustic computation, only the post-processing must be re-done.
- This restart capability also allows the smart handling of results for multiple RPM (with different frequencies for each RPM).
- ACTRAN have special capabilities to read large amount of structural data.

Modeling Steps – Acoustic Model



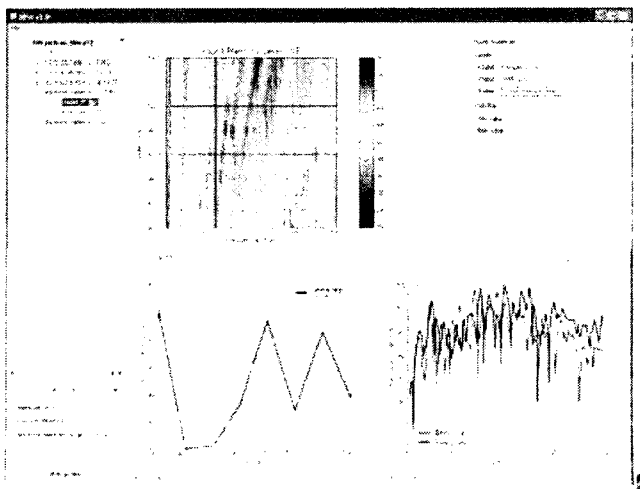
3D mesh generation

- There are several meshing tools on the market allowing fast 3D mesh generation.
- Wrapping functions (in ANSA or other) will create for you a closed external surface of your structural model. This surface will carry the structural information.
- The 3D elements are easily generated with any meshing tools.
- Automatic meshing routine are available for ANSA.



Waterfall Diagram

- Dedicated tool to post-process efficiently results on waterfall diagrams

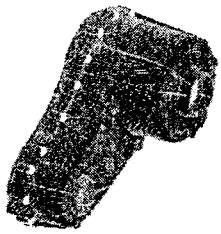


BorgWarner Automotive

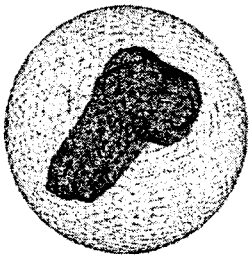
Case Study: Gearbox (1/2)

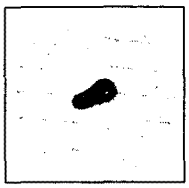
- BorgWarner was doing acoustic simulations with a BEM solver for assessing the noise radiated by its mechanical components
- BorgWarner engineers faced a major issue:
  - the computation times were too long hence it was difficult to respect the design schedules

Nastran Model



Actran IE/FE





microphones location

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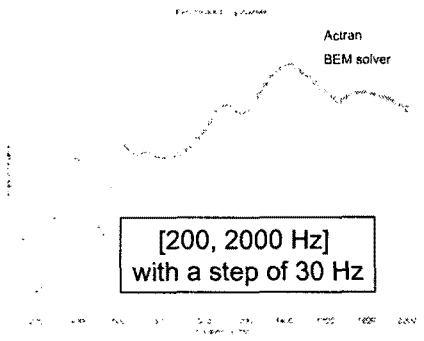
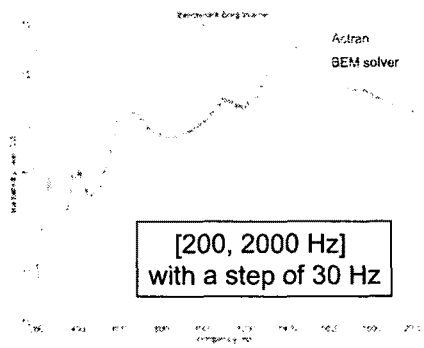
BorgWarner Automotive

Case Study: Gearbox (2/2)

Pressure at master microphone



Radiated power



- Performance, single loadcase:
  - BorgWarner BEM Software: 1.5 hours (Xeon 64 bits machine)
  - Actran: 8 minutes (Dell PC)
  - A multiple loadcase would not take much more time

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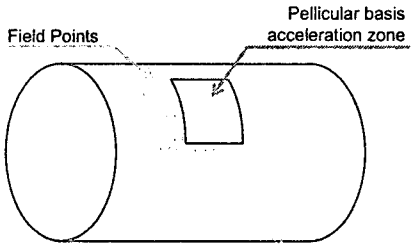
Using ACTRAN/AR for reconstructing the velocity field from pressure measurements

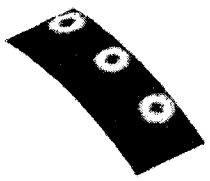
- ACTRAN/AR may be used in an inverse mode:
  - Experimental data is available for the pressure at a set of microphones
  - ACTRAN/AR reconstructs the normal velocity field on the vibrating surface
- Test case retained



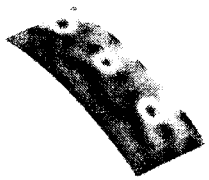
With/without admittance

- Realistic velocity patterns are chosen

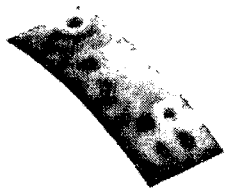
Quality vs. # of microphones



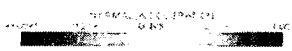
1250 microphones

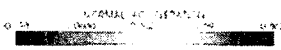


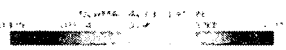
250 microphones



50 microphones







Summary: key features for AR

- Source import
  - Direct import from Nastran, ANSYS
  - Direct import of all the RPM from the files containing the structural results
- Solver
  - Direct computation of all RPM (multiple load case): one matrix resolution with multiple RHS
  - Efficient solvers (MUMPS, SPARSE, Iterative)
  - Frequency parallelisms available for very large problems
- In practice
  - Small problems run on a desktop
  - Large problems can exceed 3kHz on a car engine
- Easy to mesh
  - 3D model created in a few minutes thanks to the unequal meshes.
- ... And all the Actran standard features

Complete Industrial Process