New Techniques for Meeting Efficiently Acoustic and Vibro-Acoustic Modeling Challenges of the Aerospace Industry

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Free Field Technologies

Introduction

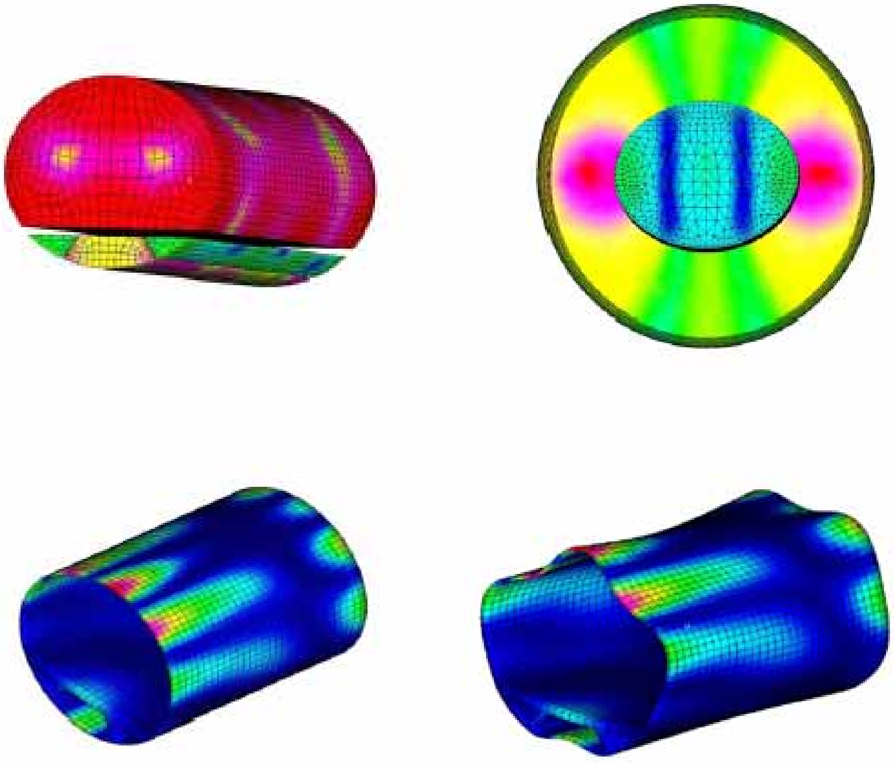
Abstract

MSC.Actran in a nutshell...

Noise transmitted to the cabin/cockpit

1. Modeling Trim
2. Modeling Random Excitation
3. Putting Everything Together

Conclusion



Abstract

The new MSC.Actran software features a wealth of capabilities for modeling accurately some challenging problems of the aerospace industry.

Two specific problems will be addressed and presented in details:

1. A specific library of finite elements has been developed, allowing to model fuselage trim components. This library is very helpful for the selection of materials, the definition of their position on the fuselage as well as the definition of the necessary thickness of the different layers.
2. Specific routines have been implemented for modeling random vibro-acoustic excitations as observed in launch conditions (spacecraft) or flight conditions (large passenger airliner). These routines include an automatic representation of an acoustic random diffuse field and an efficient representation of turbulent boundary layer excitations. Such acoustic diffuse fields can be used straightaway for modeling the interior acoustic field of a spacecraft fairing in launch conditions. The turbulent boundary layer fields can be used to represent the exterior loading on the fuselage of large aircraft in flight conditions.

MSC.Actran in a nutshell...

Finite element and infinite element based

Material library:

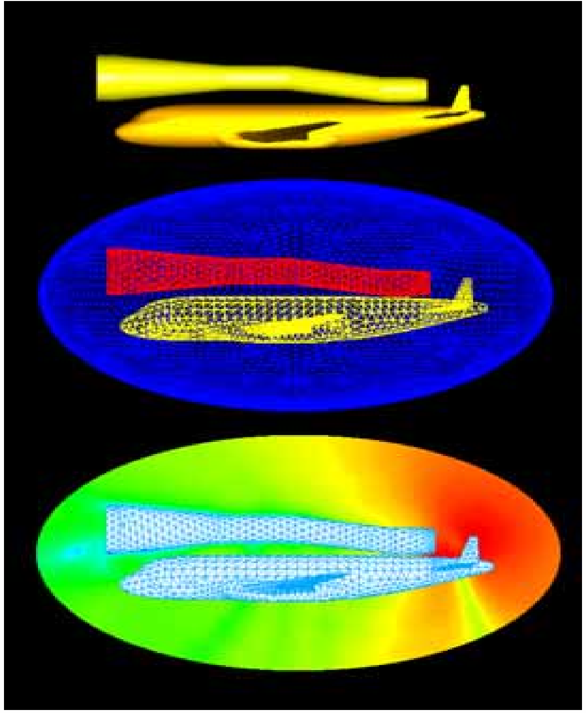
- Acoustic FE and IE,
- Visco-elastic solid & shell,
- Porous rigid (Craggs),
- Poro-elastic (Biot),
- Thin layer with visco-thermal loss

Excitations:

- Structural
- Acoustical

Solvers:

- Skyline
- Parallel solvers (SuperLU & OOC)
- Fast FRF Krylov solver



Noise transmitted to the cabin/cockpit

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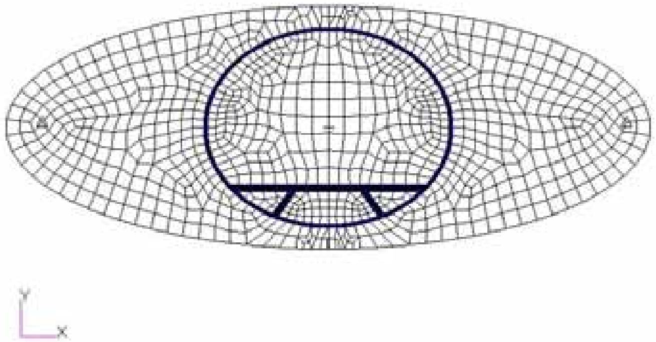
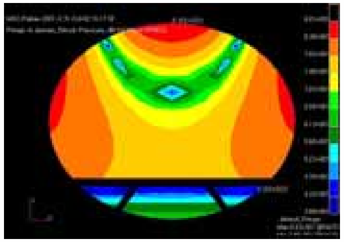
Global Challenge:

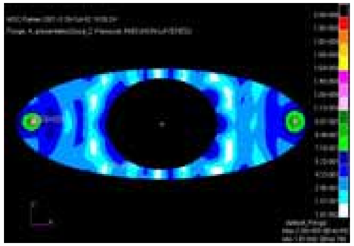
- Calculate how much of the engine noise and TBL noise is transmitted to the cabin (through the fuselage), design fuselage layers and materials for reducing transmitted noise



Solution:

- MSC.Actran used to predict the acoustic field transmitted to the cabin





Value:

- Determine the best materials and layers of the fuselage, reducing cabin overall noise

1. Modeling Trim Component

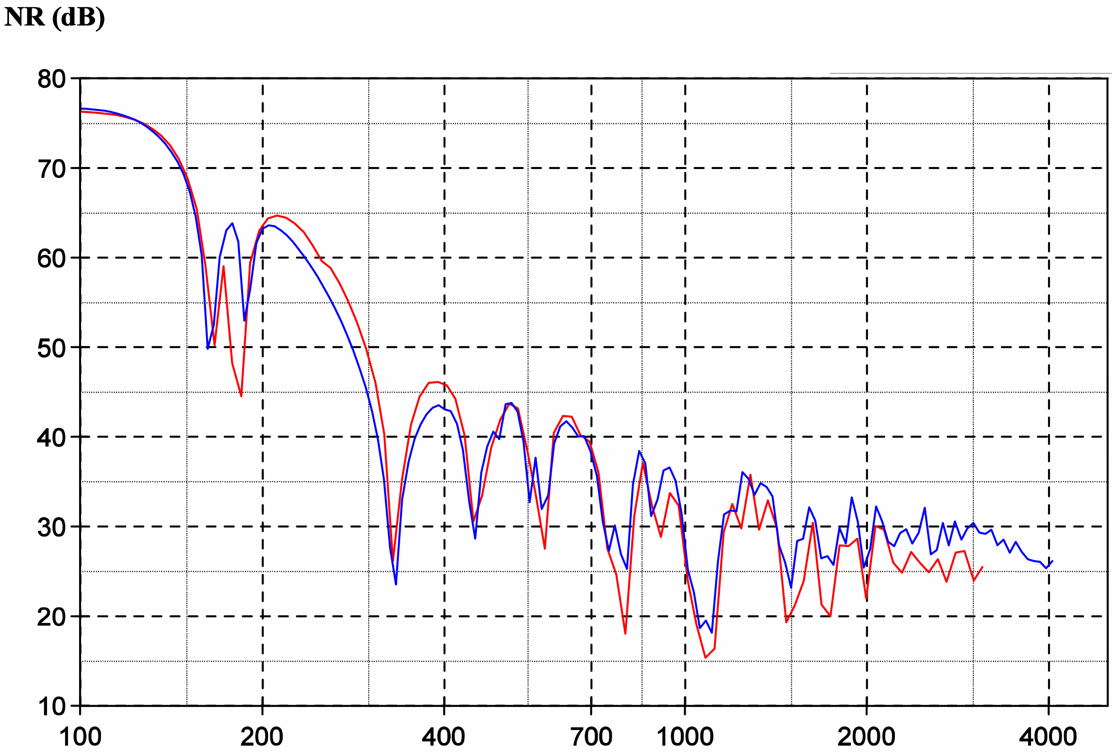
Specific library of elements

- Visco-elastic elements
- Poro-rigid and poro-elastic elements (u-p formulation)
- Acoustic layers / gaps / holes

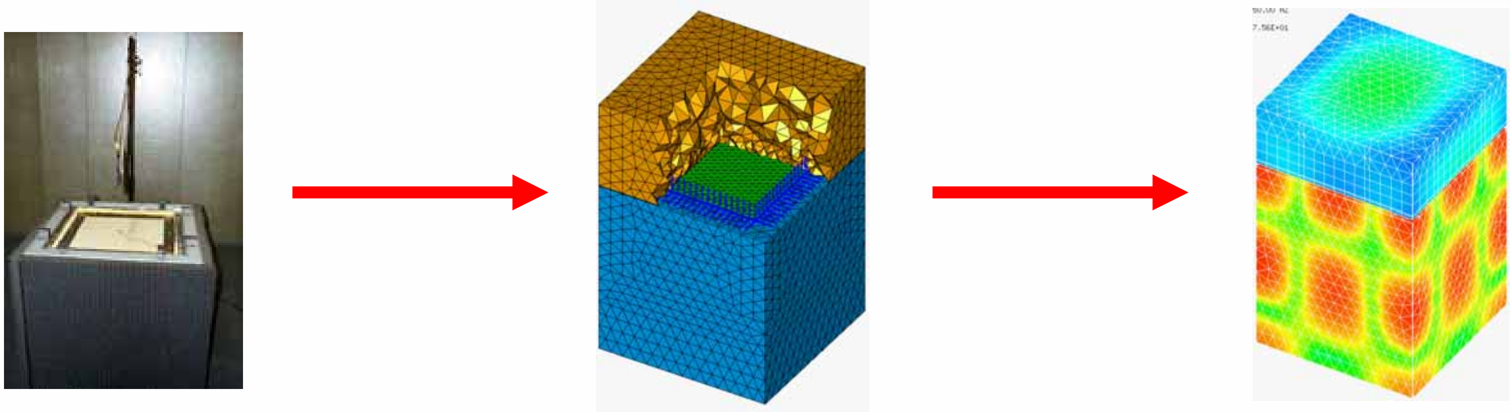
Realistic boundary conditions

- Clamping (point, line or surface contact),
- Inter-layer connections (perfect, non-perfect glue)
- Impervious surfaces

Ex1: NR of fuselage mock-up (length 1m, ϕ=0.40 m) – no trim

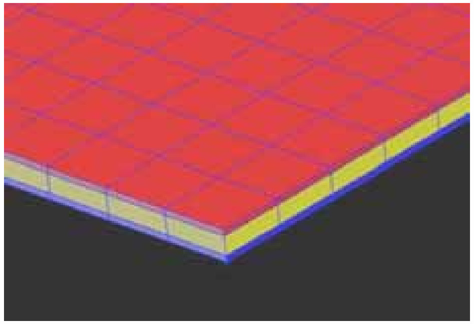


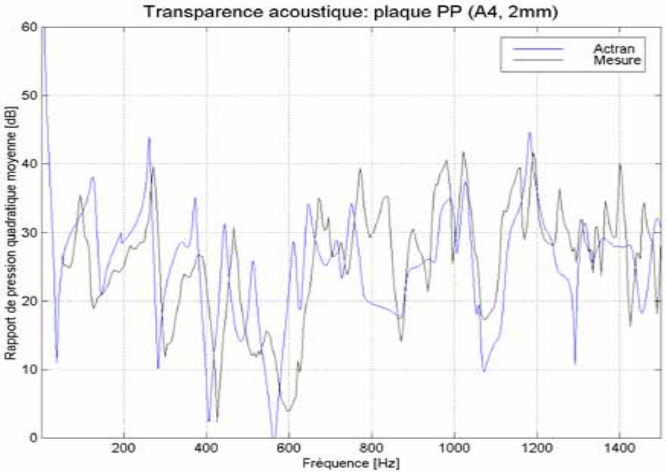
Ex2: Small Acoustic Cabin



Multi-layer panel
made of :

- aluminum
- foam
- heavy layer (carpet)





Ex3: Windscreen - correlation

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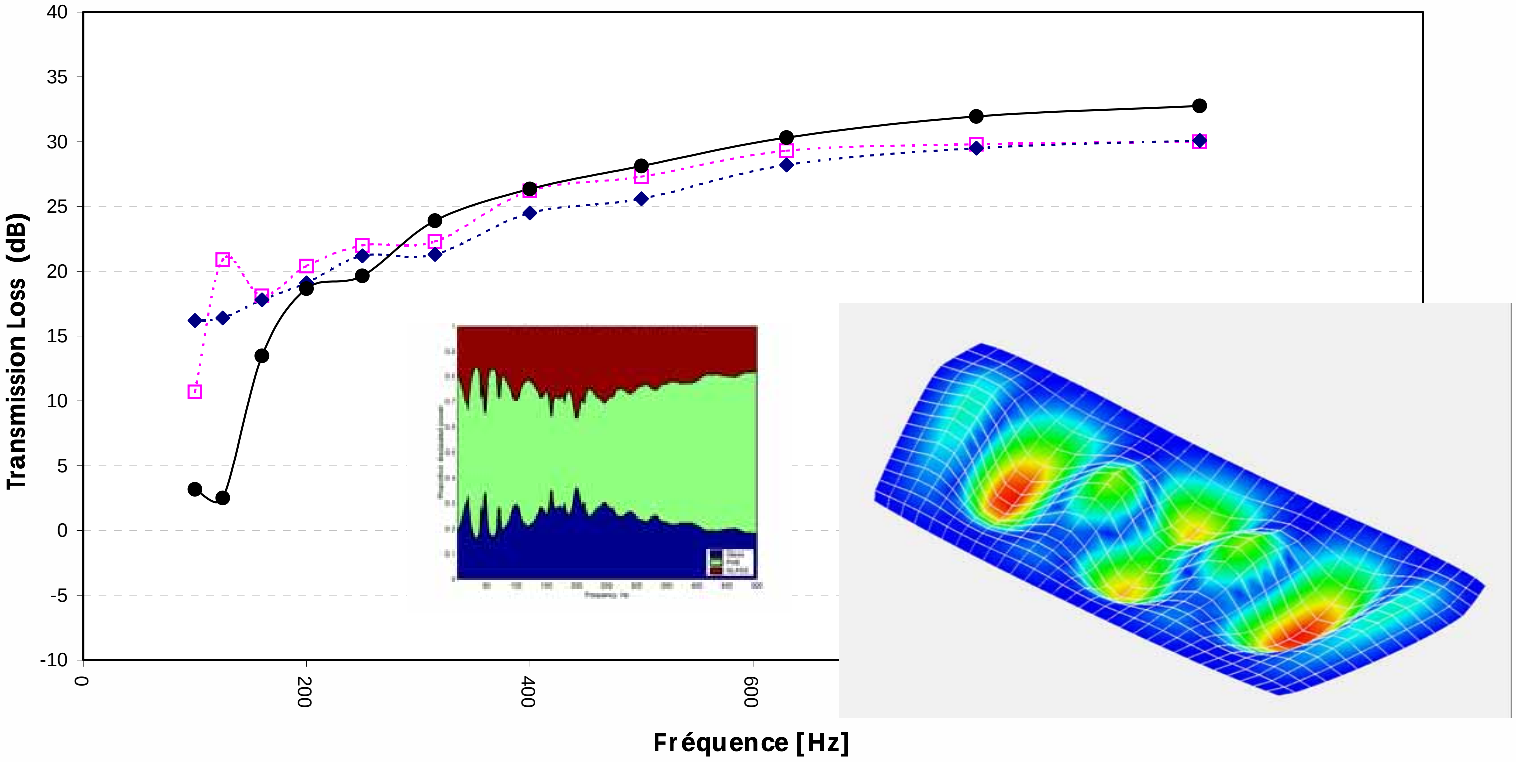

Ex4: Virtual Kundt's Tube

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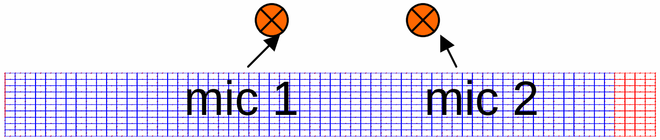

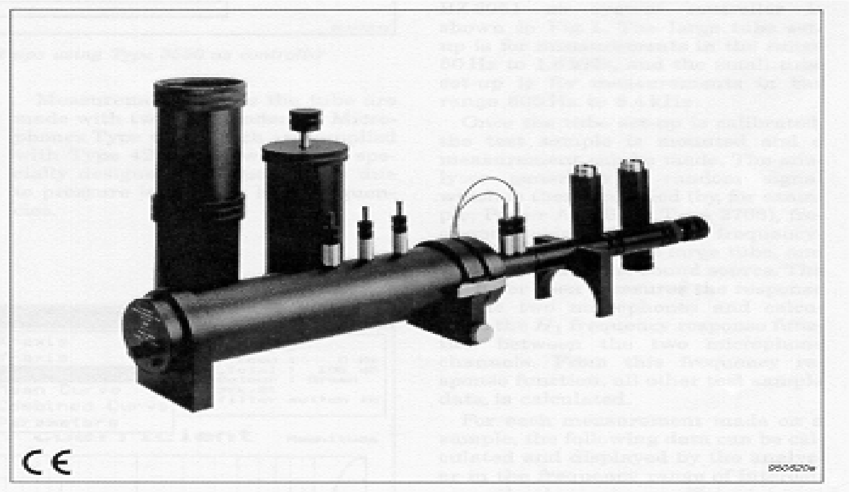

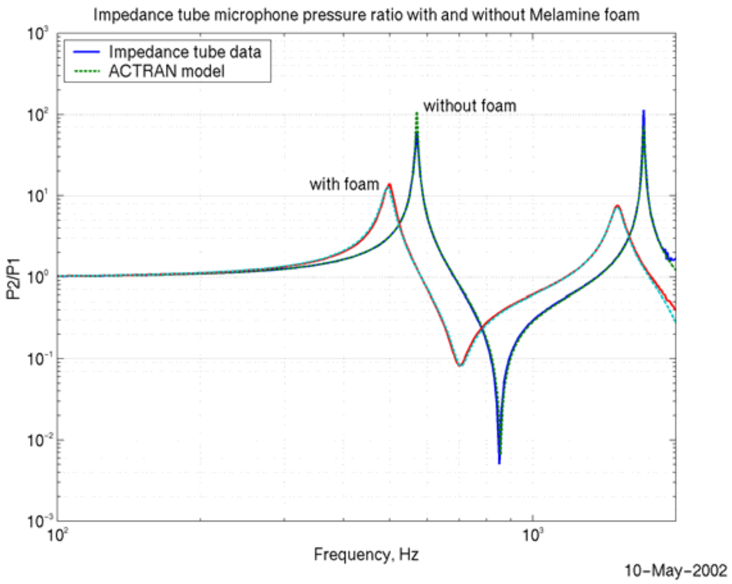

2. Modeling Random Excitations

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Spectral representation of random excitations

- Diffuse sound field
- Turbulent boundary layers (TBL)

Evaluation of random response (physical space)

- Application : antenna excited by a diffuse sound field

Evaluation of random response (modal space)

- Asymptotic modal approach for TBL’s
- Application : plate excited by a turbulent boundary layer

Spectral representation of random excitations

Random excitations

- modeled as distributed & weakly stationary random process
- Characterized by: cross-power spectral density
  = product of
  - power spectrum (PSD at a reference point),
  - spatial correlation function,

$$S\left(x_i, x_j, \omega\right) = S_{\mathrm{ref}}\left(\omega\right) f\left(l_{ij}, t_{ij}, \omega\right)$$

Spectral representation of diffuse field

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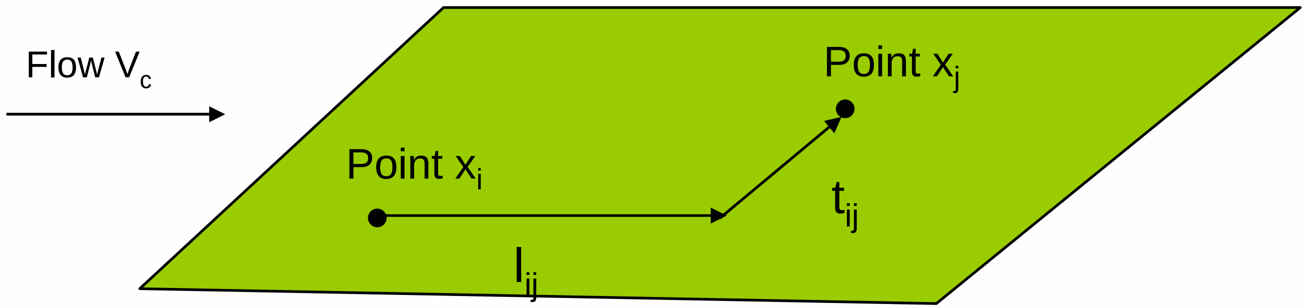
- The Institute of Noise Control Engineering (INCE) defines a diffuse sound field as
  “ *a sound field in which the time average of the mean-square sound pressure is everywhere the same and the flow of acoustic energy in all directions is equally probable*”
- Produced experimentally by activating acoustic sources in a reverberant chamber
- Obtained mathematically through a superposition of an infinite number of plane waves with different propagation directions
- Cross-power spectral density $S\left(x_i, x_j, \omega\right) = S_{ref}\left(\omega\right) f_d\left(\mathbf{x}_i, \mathbf{x}_j, \omega\right)$ with

$$f_d\left(\mathbf{x}_i, \mathbf{x}_j, \omega\right) = \frac{\int \exp(-i\mathbf{k}\cdot(\mathbf{x}_i - \mathbf{x}_j))\, d\mathbf{k}/|\mathbf{k}|}{\int d\mathbf{k}/|\mathbf{k}|} = \frac{\sin(|\mathbf{k}||\mathbf{x}_i - \mathbf{x}_j|)}{|\mathbf{k}||\mathbf{x}_i - x_j|}$$

Spectral representation of TBL

- Usual descriptors for flat/nearly flat structures:
- Power spectrum: Goody model (Goody, 2002)
- Spatial correlation function: Corcos model (Corcos, 1963)

$$f_c\left(l_{ij}, t_{ij}, \omega\right) = e^{-\frac{\alpha_c \omega |l_{ij}|}{V_c}} \, e^{-\frac{\beta_c \omega |t_{ij}|}{V_c}} \, e^{-\frac{i\omega l_{ij}}{V_c}}$$



M. Goody, *An empirical spectral model of surface-pressure fluctuations that includes Reynolds number effects*, AIAA Paper 2002-2565, 8th AIAA/CEAS Aeroacoustics Conference and Exhibit, June 17-19 2002, Breckenridge, CO.

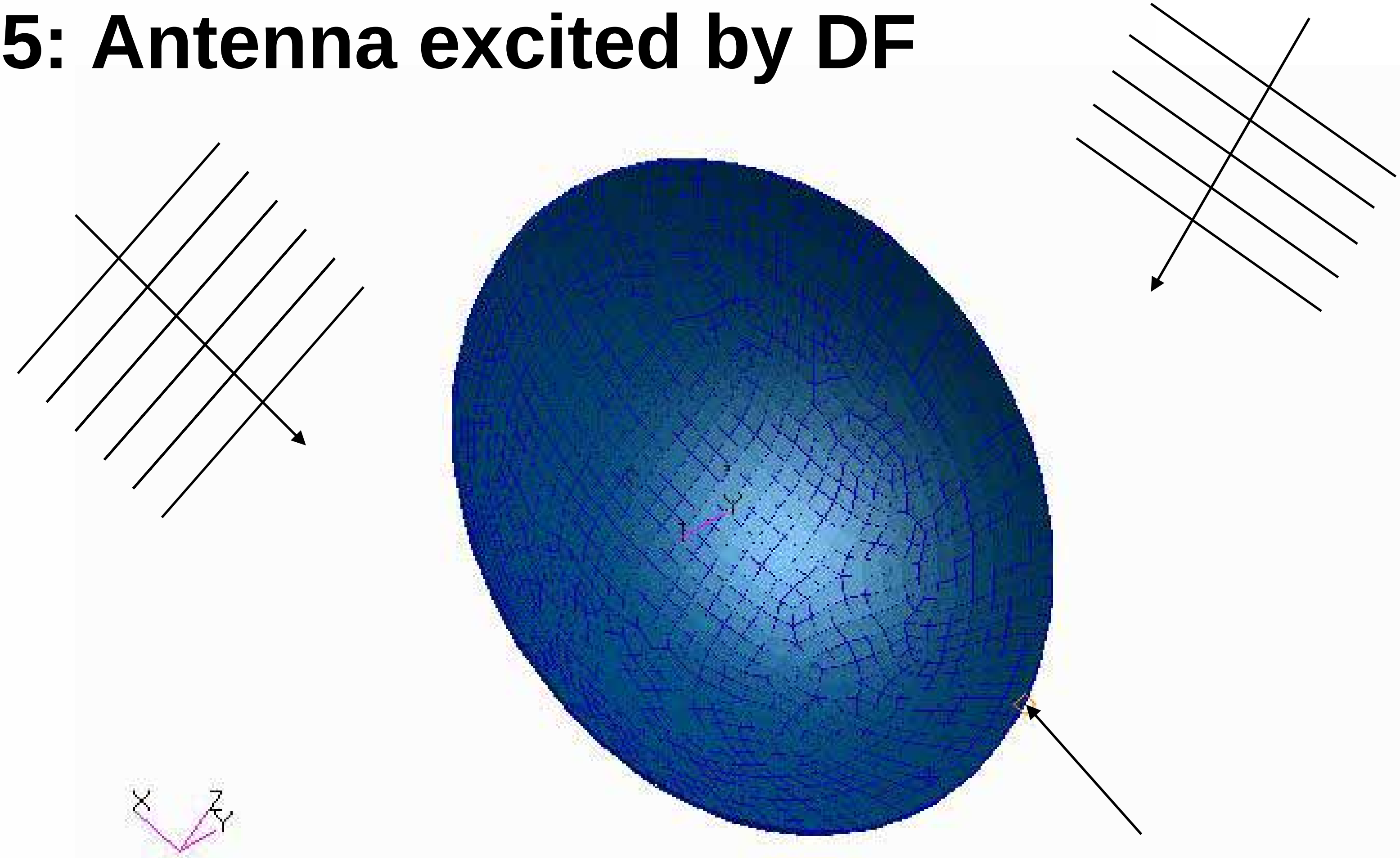
G. M. Corcos, *Resolution of pressure in turbulence*, J. Acous. Soc. Amer., **35**, 2, 1963.

TBL – Goody Model

- Goody proposed a semi-empirical model for S_{ref} under 2-D zero-pressure-gradient boundary layer
- The model coefficients were calibrated on experimental surface pressure spectra measured by 7 research groups
- Parameters :
  - Velocity outside the boundary layer U_e
  - Boundary layer thickness δ
  - Wall friction coefficient C_f
  - Viscosity of the fluid in the TBL ν_{bl}
  - Density of the fluid in the TBL ρ_{bl}

$$S_{ref}(\omega) = \frac{0.375\, C_f^2 \rho_{bl}^2 U_e \delta^3 \omega^2}{\left(\left(\frac{\omega\delta}{U_e}\right)^{0.75} + 0.5\right)^{3.7} + \left(1.1\left(\frac{\delta U_e C_f}{2\nu_{bl}}\right)^{-0.57}\left(\frac{\omega\delta}{U_e}\right)\right)^{7}}$$

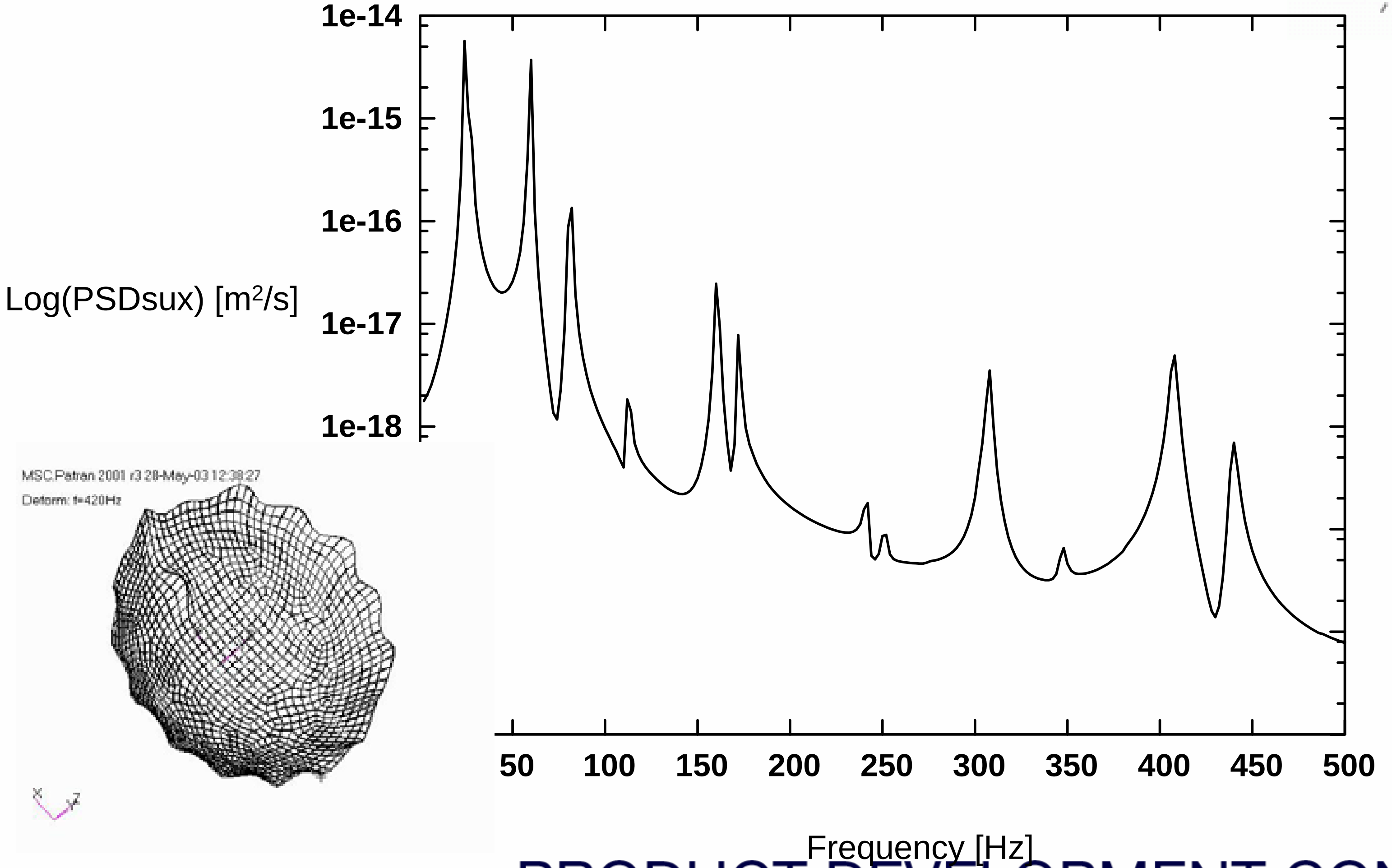
Ex5: Antenna excited by DF



Displacement set to 0 at 9 nodes at the center of the antenna

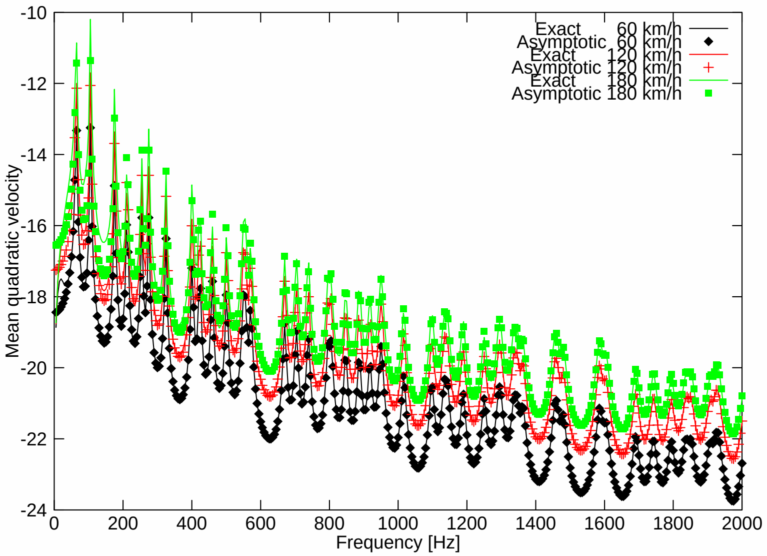
Measurement point P

Antenna - PSD of displacement



Ex6: Plate Excited by a TBL

- Aluminum plate excited by a TBL:
  - 0.75 m x 0.40 m, thickness = 0.00315 m
  - Young modulus = 7.0 10^{10} Pa, Poisson ratio = 0.23 (-)
  - Loss factor = 0.01 (-), mass density = 2409 kg/m^3
- TBL excitation:
  - Corcos model (α_c= 0.10, β_c = 0.5) with unit PSD
  - Various values of flow velocity
- Parameters
  - Use of modes up to order 10 along each direction
  - Freq range : 5-2000 Hz, step of 5 Hz
  - Comparison of ‘exact’ and ‘asymptotic’ modal approaches.



Summary of the Random approach

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Diffuse sound fields and turbulent boundary layers can be modeled as weakly stationary processes

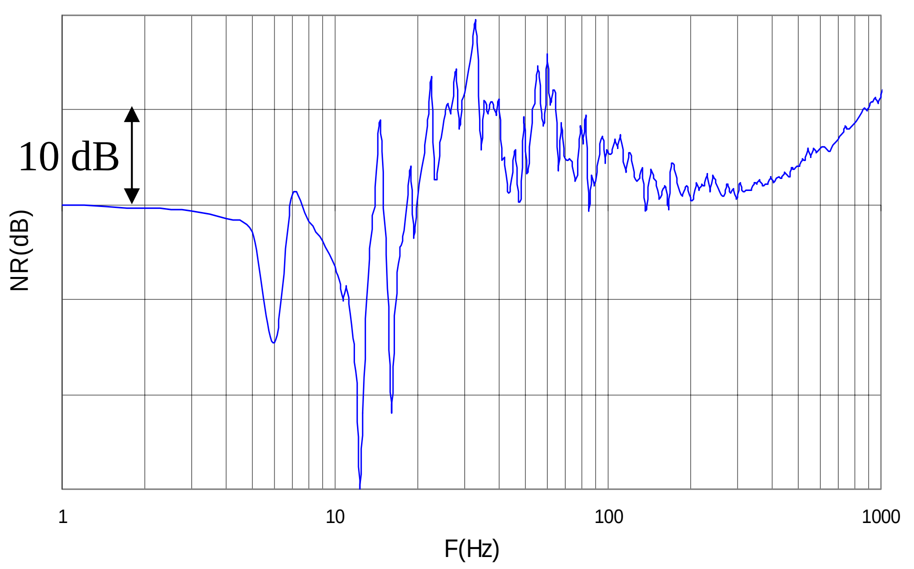
Random responses can be evaluated

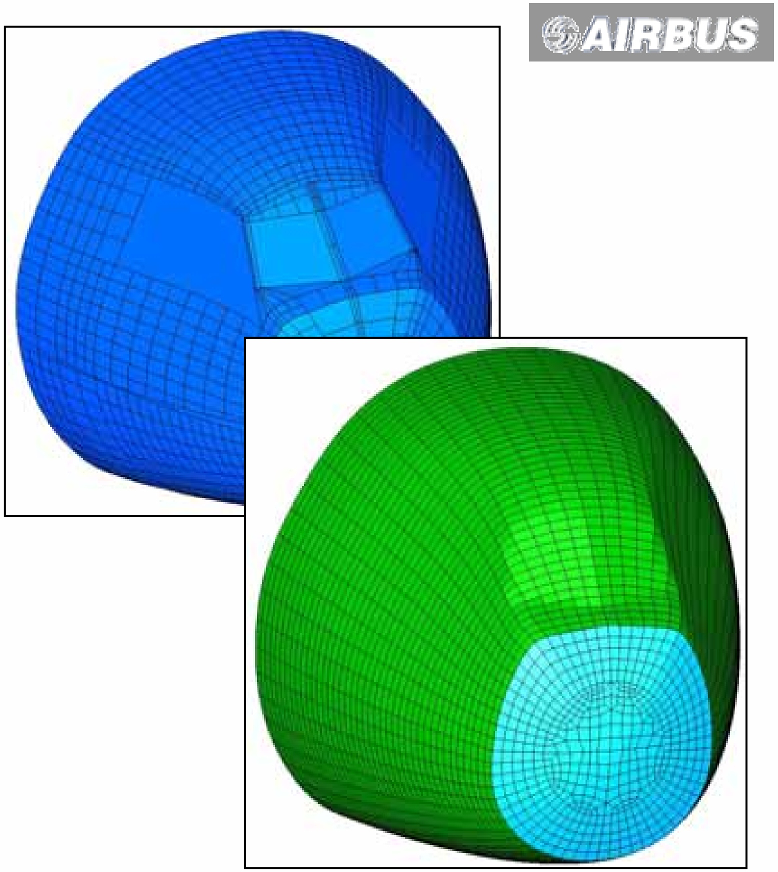
- In the physical space (the random excitation is decomposed in a set of pseudo load cases)
- In the modal space

An asymptotic modal approach, valid at high frequency, has been developed. It allows for a drastic reduction of CPU time (from hours to minutes on the application presented)

3. Putting Everything Together

- Real shape, realistic structure
- Diffused sound field
- [0Hz – 1000Hz]





Conclusion

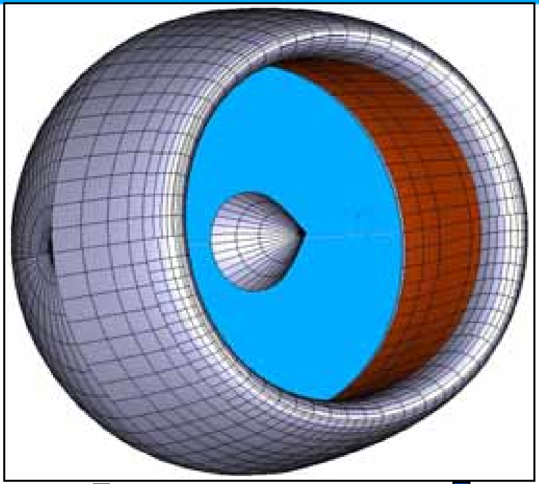
- Techniques are available for
  - Modeling accurately trim components
  - Modeling realistic excitations (diffuse field, TBL)

- Efficient solving procedures have been developed

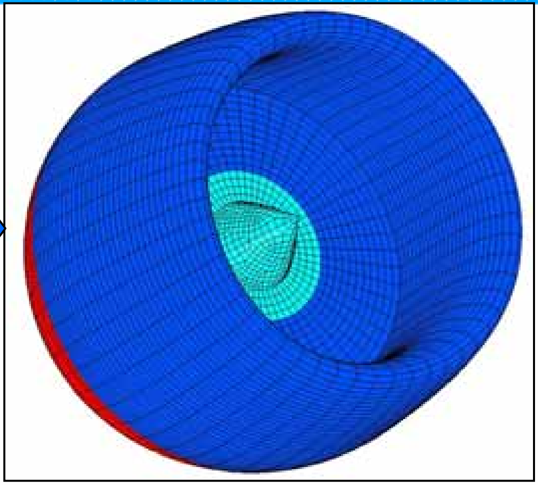
- Combining all these ingredients leads to realistic simulation of aerospace challenging problems, like f.e. the insulation of the cockpit

- Other excitations could be considered, like the aircraft turbofan noise which can be accurately modeled – see next slide

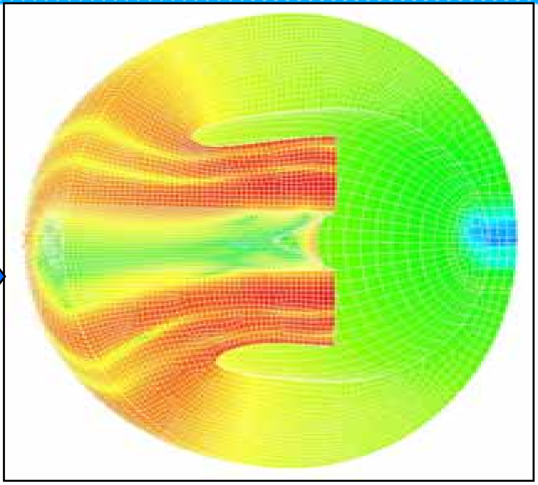
Aircraft engine intake - SPL



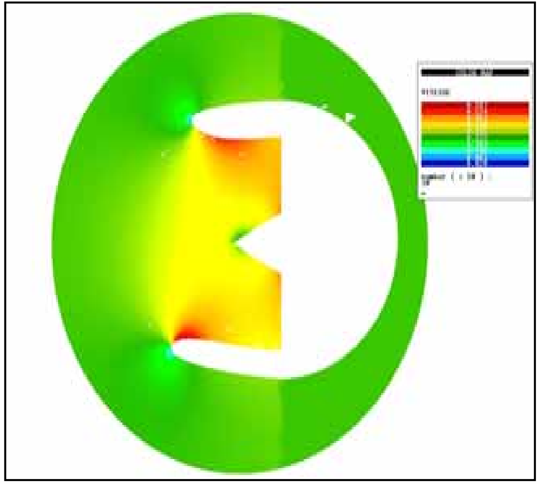
CAD



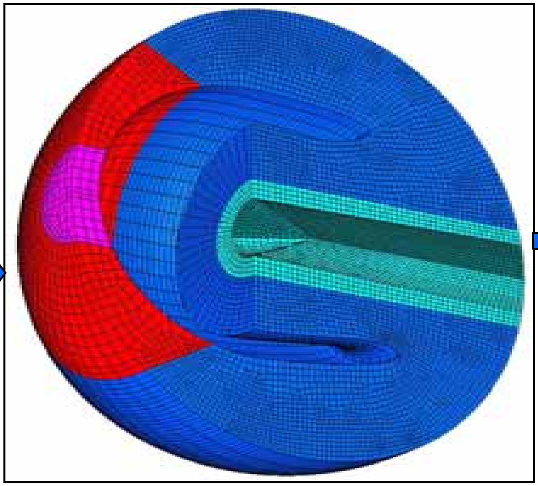
Projected Mesh



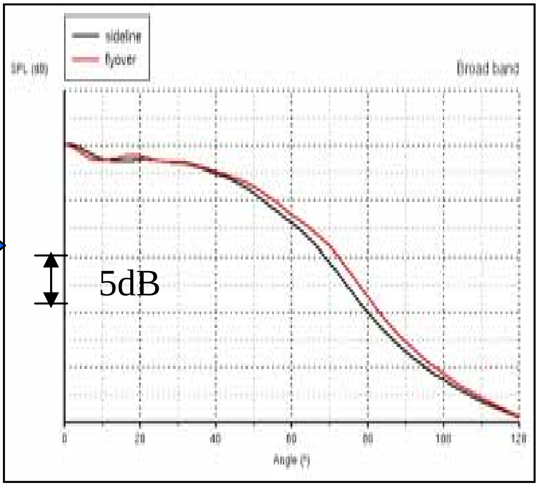
SPL - mode (8,3)



Interpolated flow field



Acoustic Mesh



SPL - Broad band