dBVISION

01dB-METRAVIB

Acoustical imaging techniques and Holography

Industrial Applications

P. CHEVRET - D. VAUCHER de la CROIX
01dB-METRAVIB – *Industries*

Meeting of the Swiss Acoustical Society – RAPPERSWIL – November 2004

For large structures

..or small ones!

Application domains

1 - Underwater

2 - Aeronautics

3 - Automotive

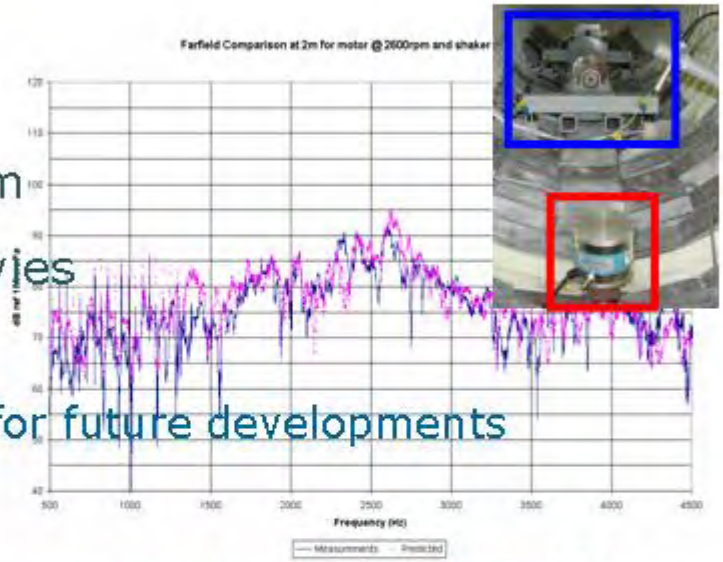
4 - Other industrial applications

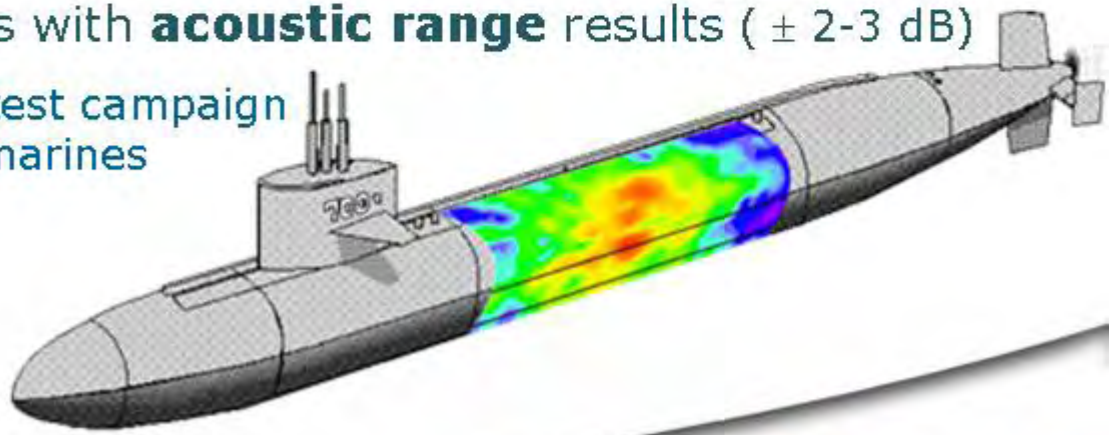
5 - 3D extensions

Underwater applications

❑ dBVISION MARINE

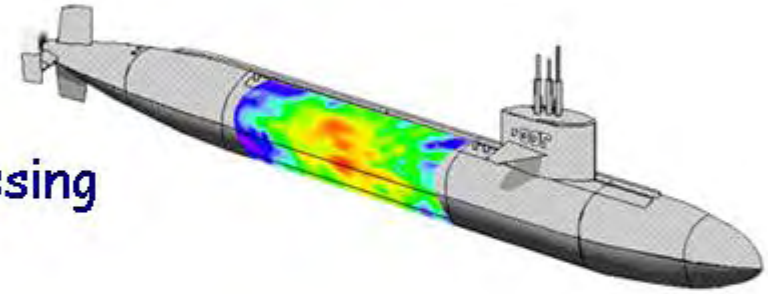
- ✓ A mobile acoustical imaging platform
- ✓ "Sponsorship" of the Asia/Pacific Navies
  - o DSTO Australia, DSO Singapore
  - o Strong involvement of MTC Pakistan for future developments
- ✓ Multiplan & Cylindrical arrays
- ✓ Excellent comparisons with **acoustic range** results (± 2-3 dB)
  - o Joint US/Australian test campaign on Collins class submarines





Underwater applications

The 6 steps in signature management with dBVISION



1 - Monitoring set-up

2 - Data acquisition and pre-processing

3 - Data processing

4 - Relevant frequencies identification

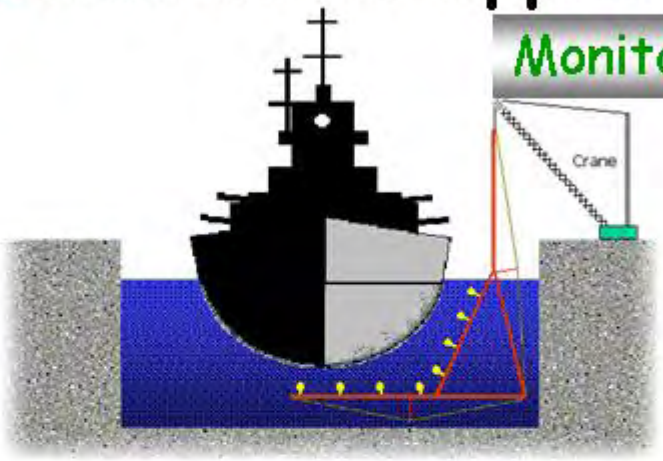
5 - Acoustic mapping of part of the vessel

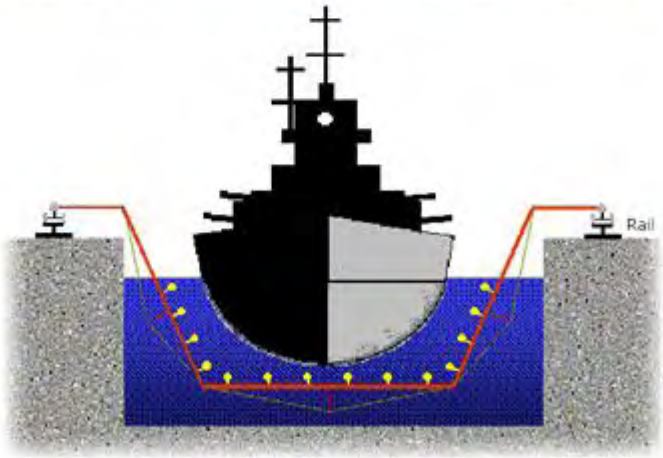
6 - Radiated farfield assessment

dB VISION

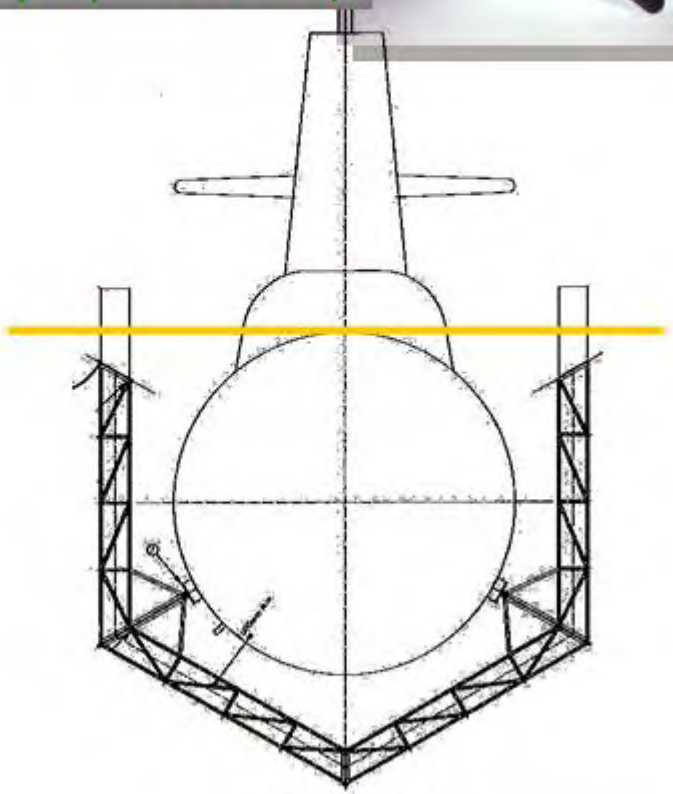
Underwater applications

Monitoring set-up: polyline array





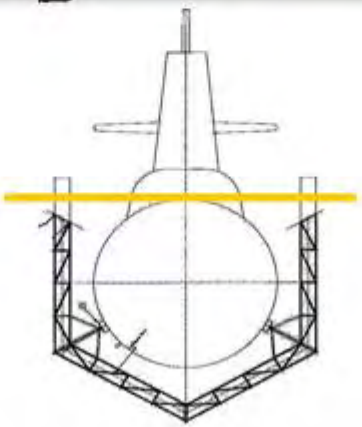
Trials in Harbour basin

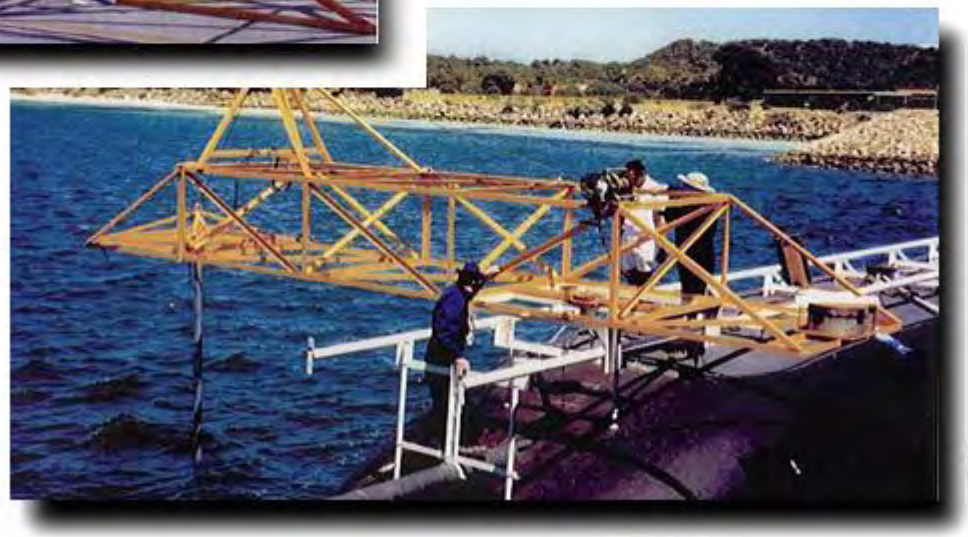


Trials at Sea

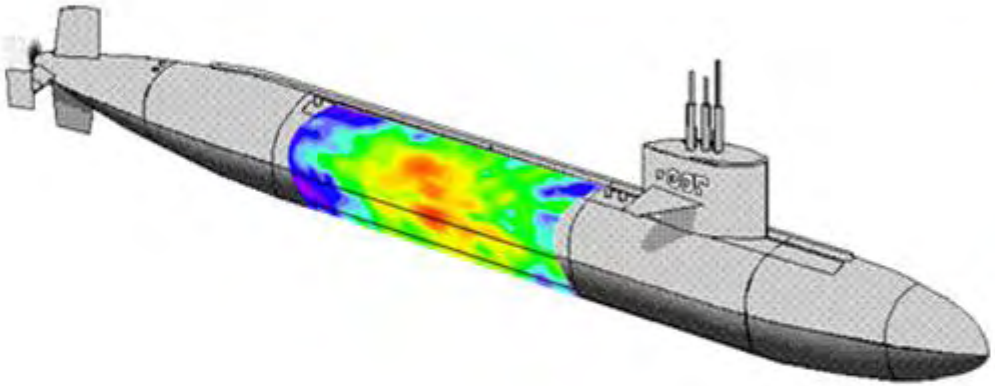
Underwater applications

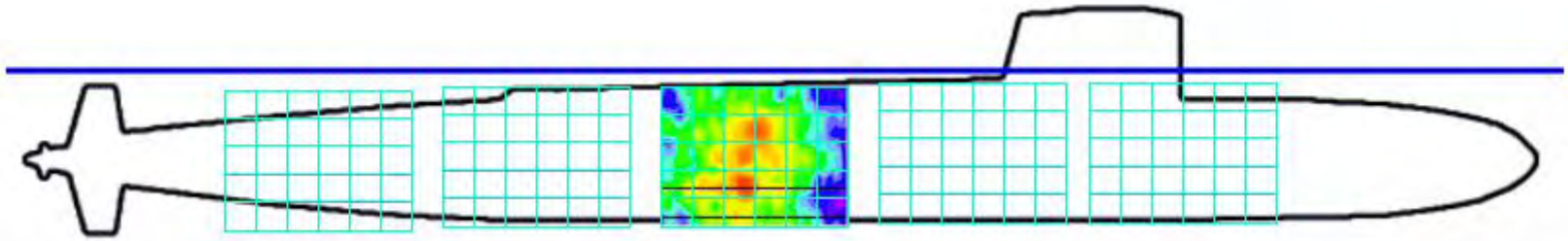
Monitoring set-up
Frame array





Underwater applications

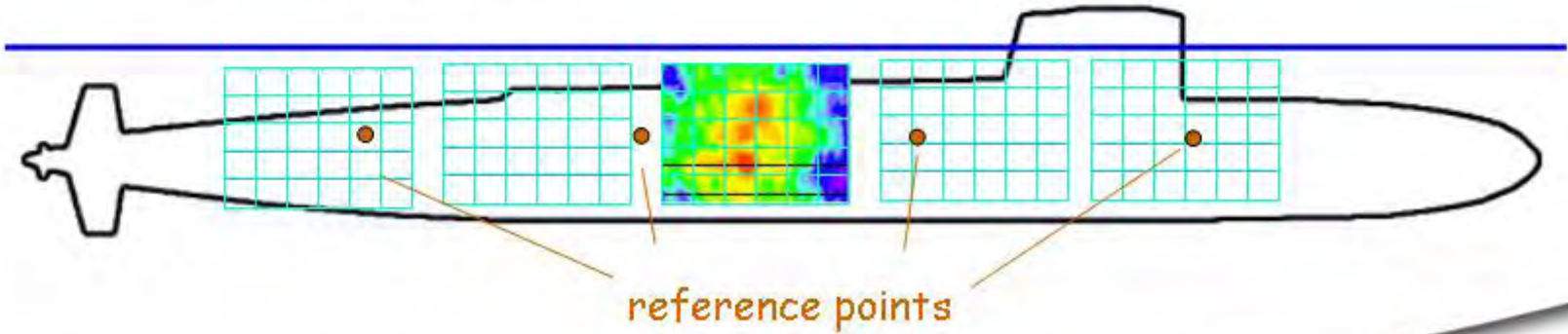




Underwater applications

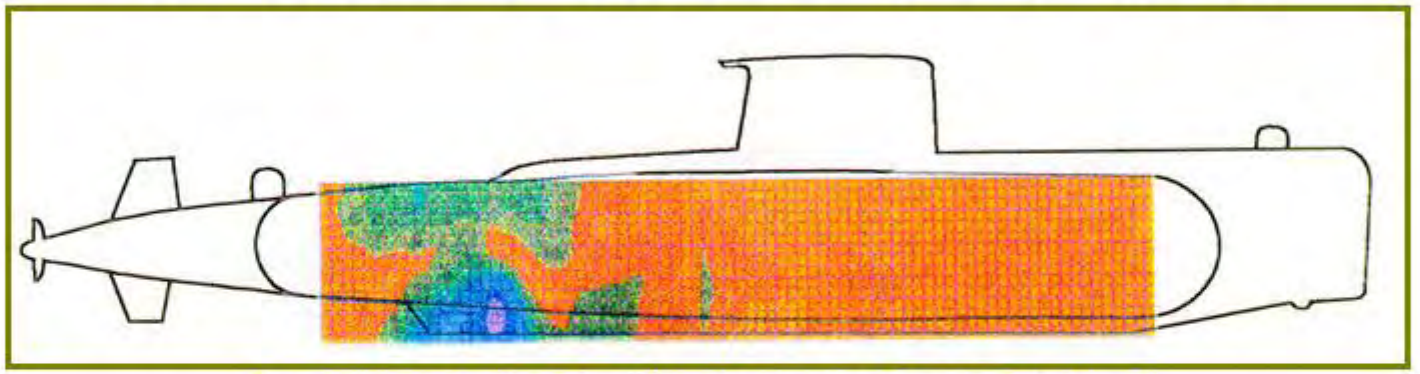
Data acquisition and pre-processing

- simultaneous measurements on many points
  - ☒ define a regular or irregular measurement meshing
  - ☒ use adequate interpolation technique for homogenization
  - ☒ add phase references, stationary sources to build larger synthetic array

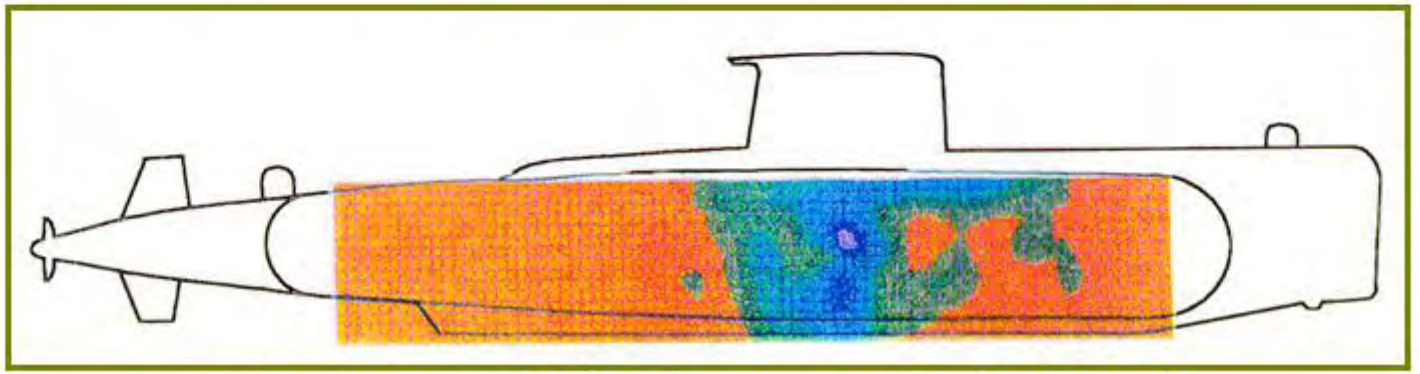


Underwater applications

Localisation and Assessment of local sources



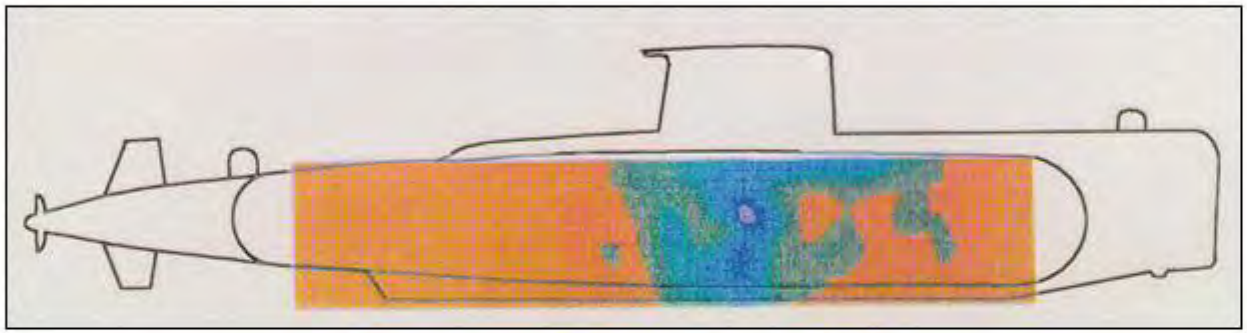
Statement: back, frequency F1, Machine A



Statement: middle, frequency F2, Machine D

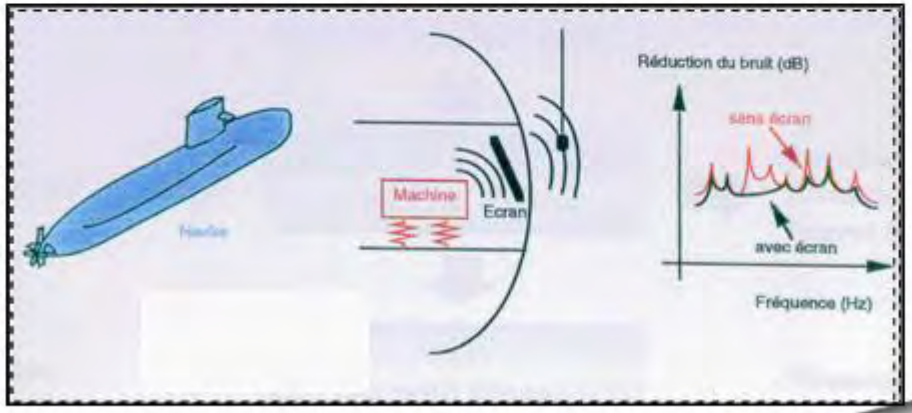
Underwater applications

Localisation and Treatment of local sources



frequency F2, auxiliary AX4

Acoustic weakness due to typical machinery and possible noise reduction applying an adequate source screening procedure

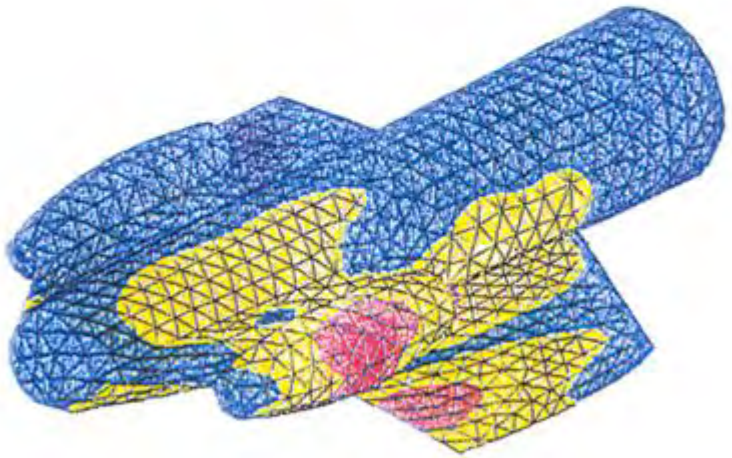


Aeronautic applications

1 - Cabin acoustic design

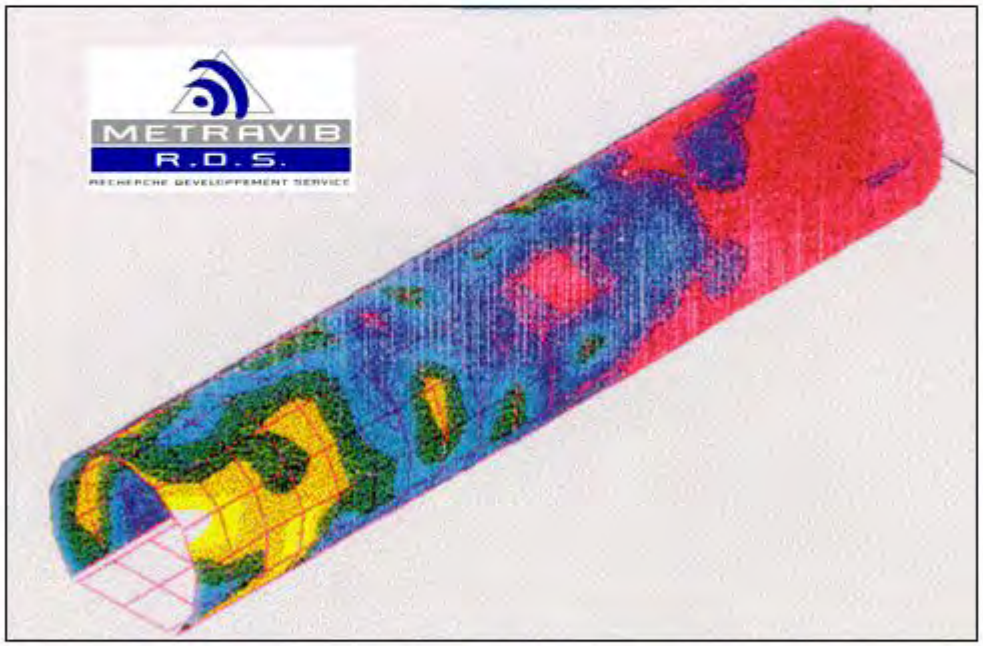
2 - Engine noise measurement

3 - Connection to vibroacoutics



Aeronautic applications

Cabin acoustic design



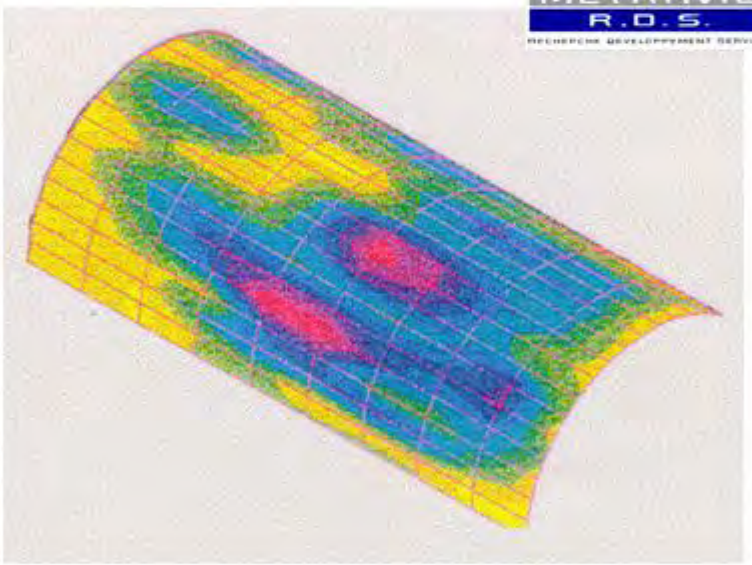
Measurement inside aircraft cabin
Acoustic pressure radiation

Instrumentation inside the cabin:
cylindrical antenna

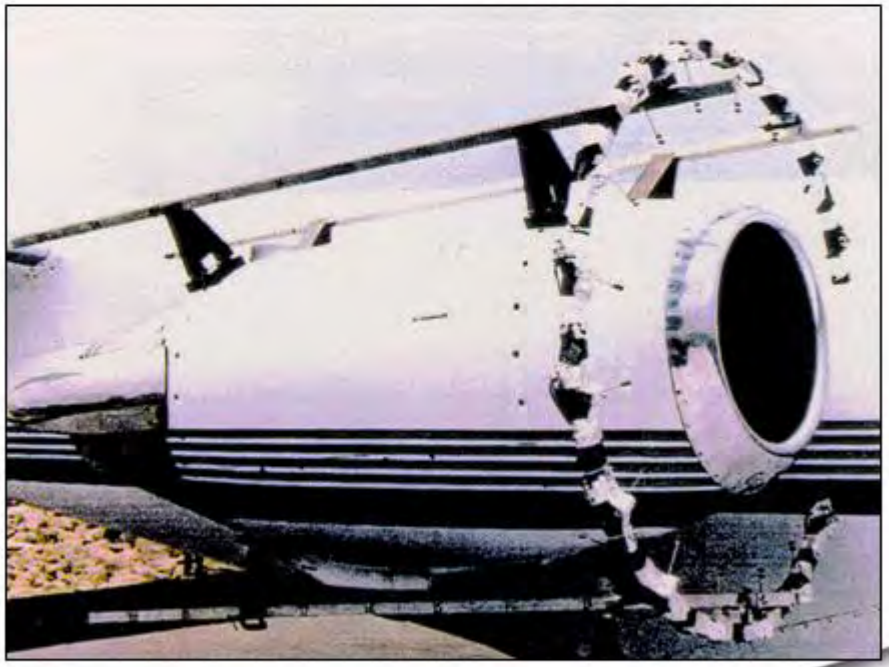
Ground and In flight tests

Aeronautic applications

Engine Noise Measurement



Measurement around the engine

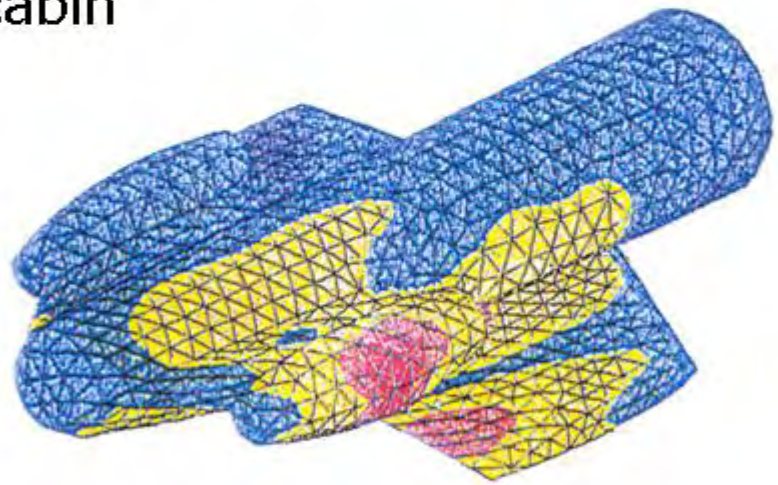


Aeronautic applications

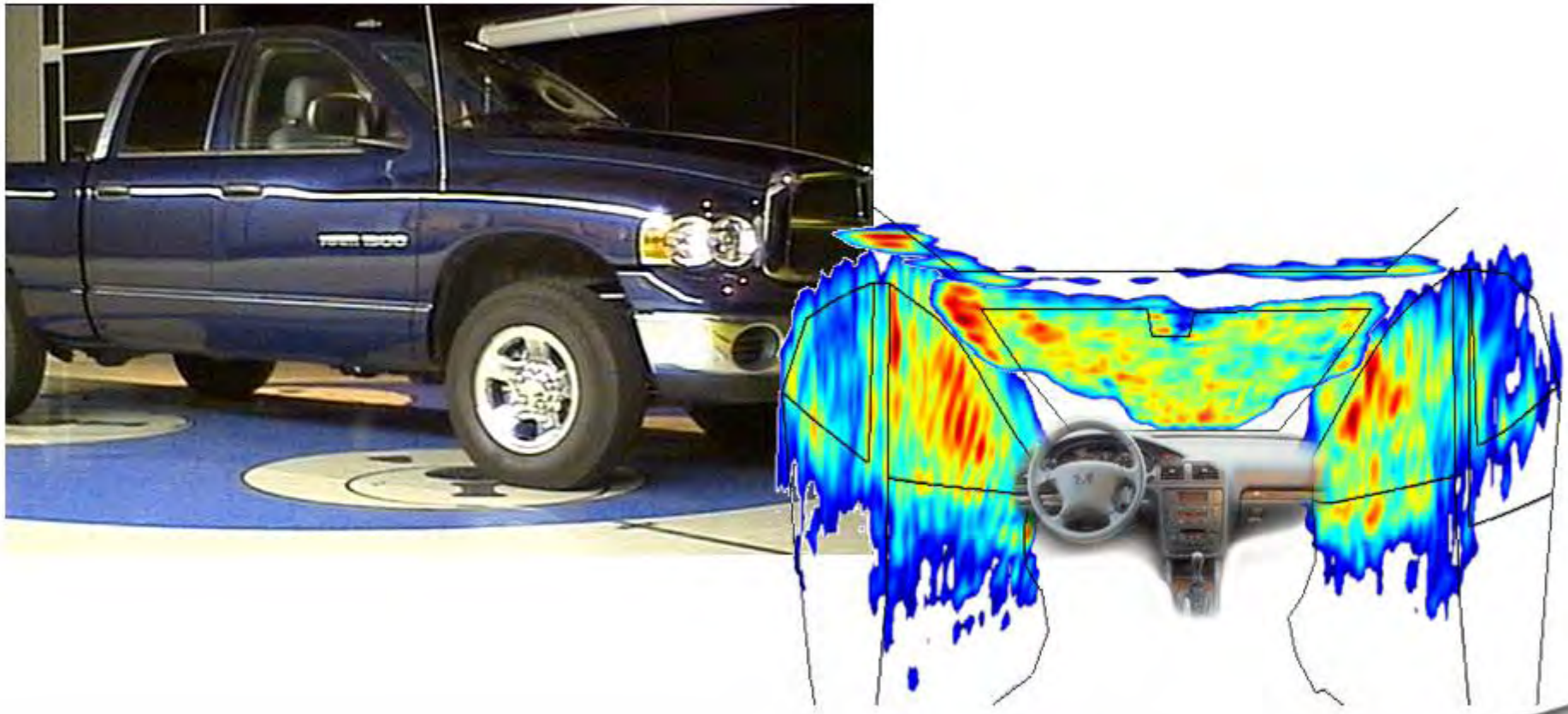
Connection to vibroacoustic prediction software (ASTRYD)

Noise reduction inside an aircraft cabin

- localisation and quantification of hot spots around the engine aircraft (LORHA)
- acoustic field computation on the aircraft fuselage (ASTRYD)
- identification of the airborne noise contribution inside the cabin



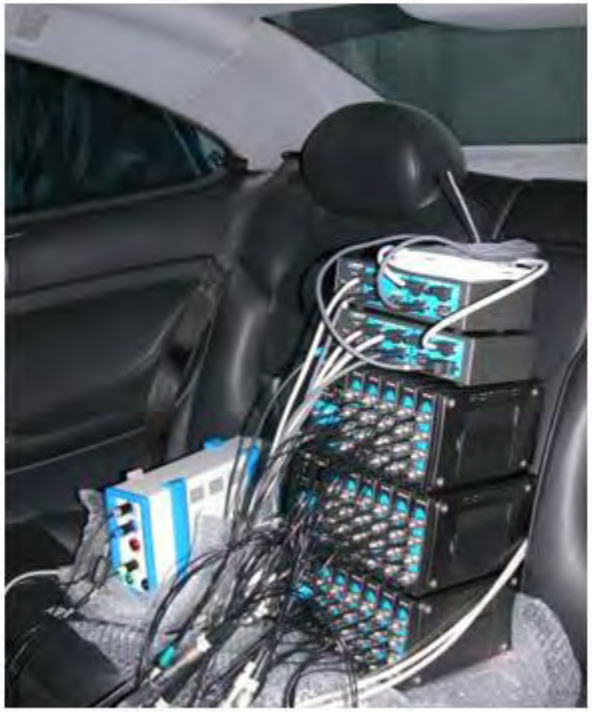
Automotive applications



Automotive applications

Standard Instrumentation for CABIN noise measurements

System set-up and cabling in a compact way inside the tested car ready for Wind tunnel operations (as an example)



- dBVISION IPS (positioning system)
- 64 microphones array
- Compact ORCHESTRA Data Acquisition Front End

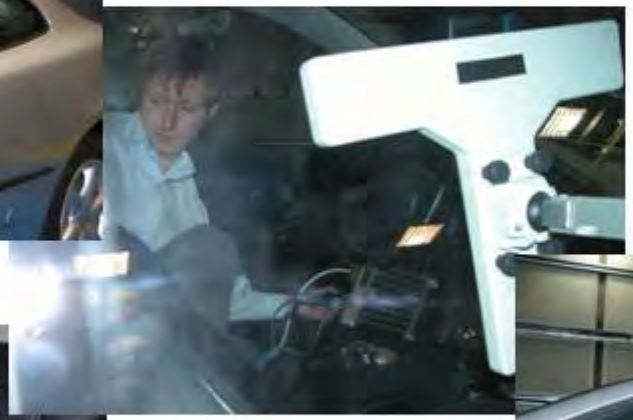
Automotive applications

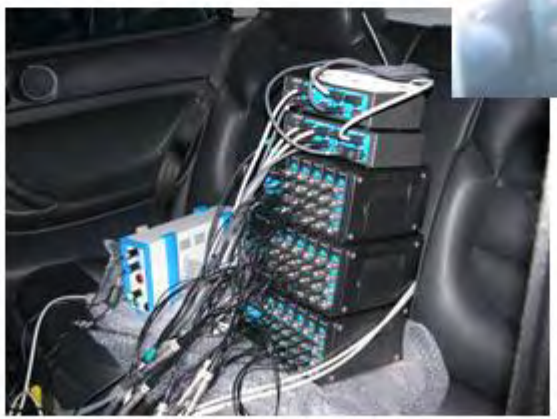
Standard Instrumentation for CABIN noise measurements

dBVISION IPS (positioning system) and 64 channel array

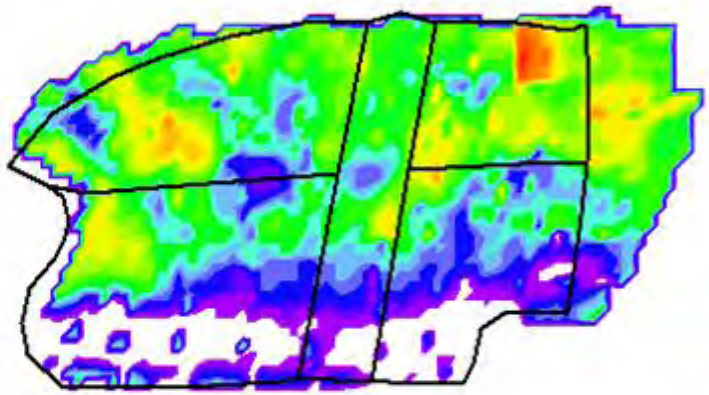
Automotive applications

- Performing Measurements inside the vehicle...

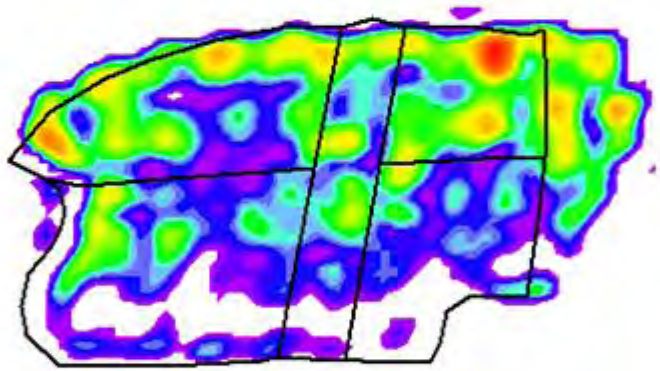




Automotive applications



Measurement



Back propagation

Benefits of NAH vs. standard pressure measurements

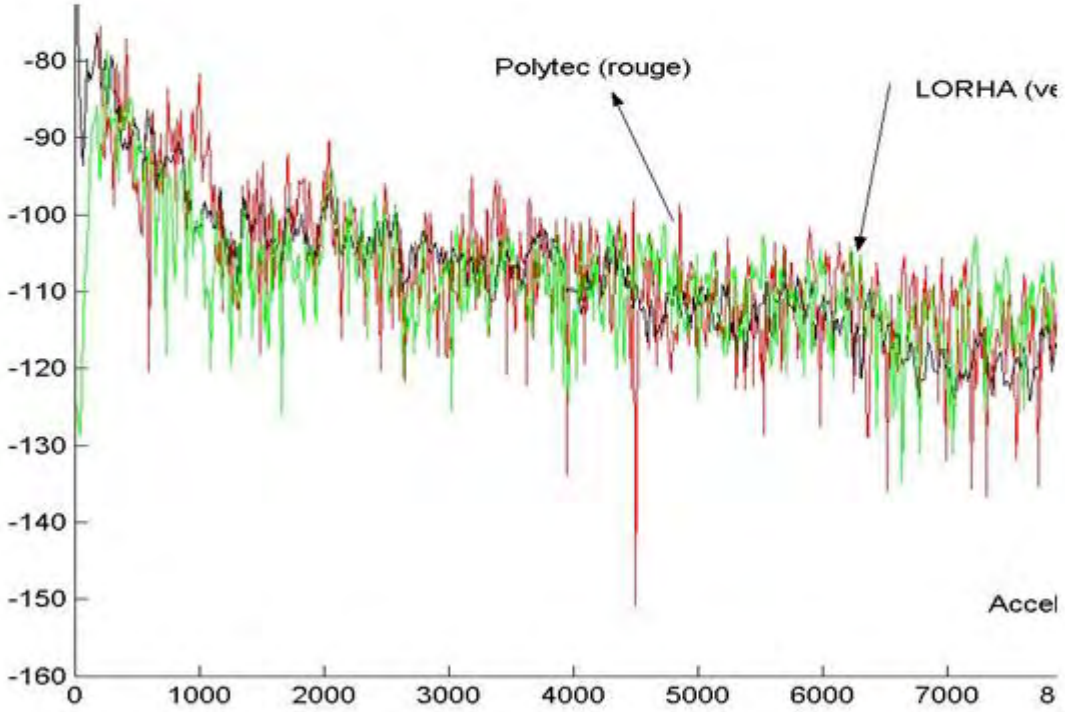
- focus on windows and leak systems (components)
- better acoustic diagnosis (better identification)

Automotive applications

Quantification

Results on a car window

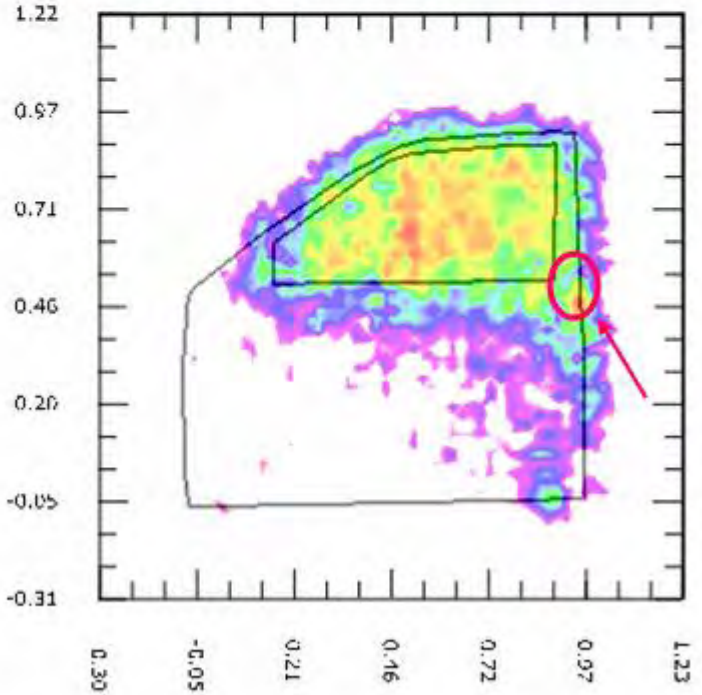
- Comparisons between:
  - velocimeter
  - accelerometer
  - holography



Automotive applications

Car Door Diagnosis

- ✓ Artificial noise source located inside (broadband loudspeaker)
  - o Typical 1/3rd octave band results

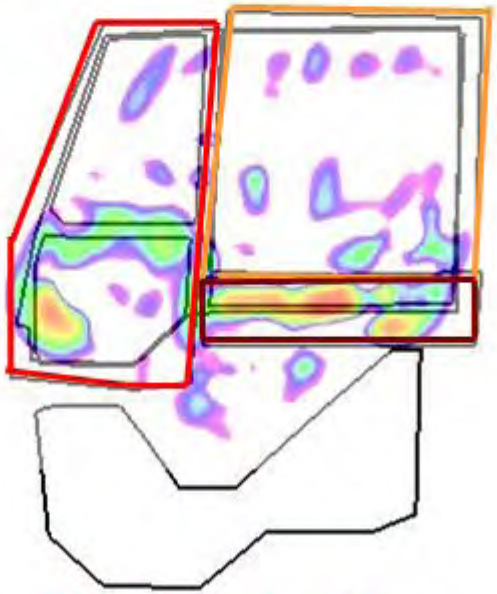


Bad fixture sealing part !!

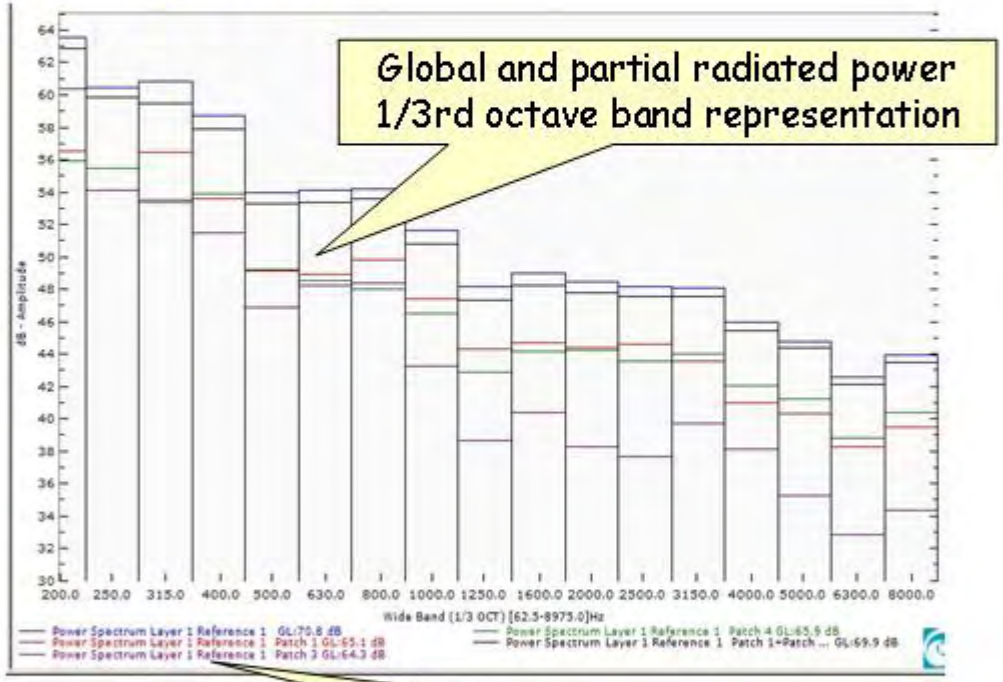
Automotive applications

Truck Door Diagnosis

- ✓ Source Ranking
  - o 1/3rd octave band results



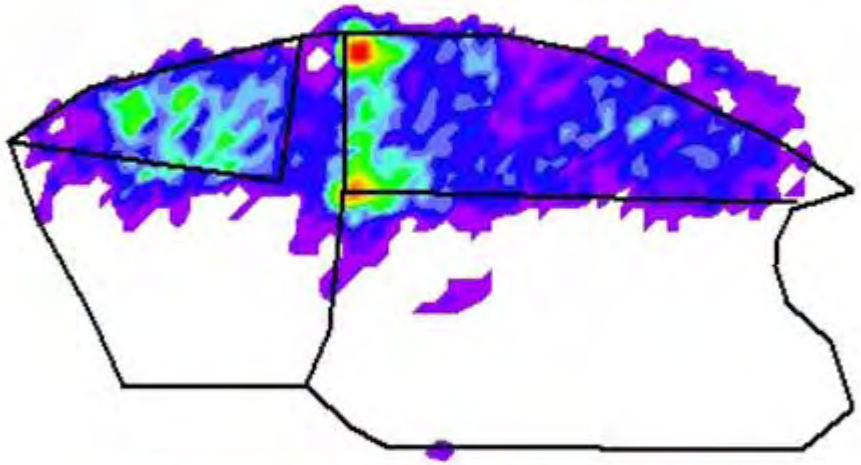
Patch definition
on example truck door



Automotive applications

Inside Vehicle Measurements

- cabin noise signature processing
- localisation of weakness parts
- complete vehicle in test room
- exterior loudspeaker excitation (diffuse field)
- presented results focused on lateral panel

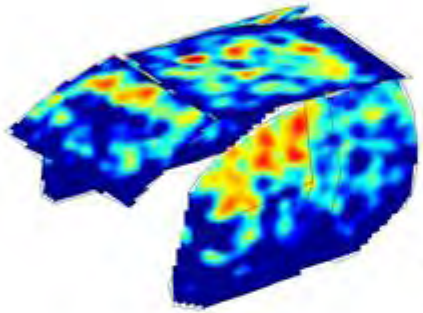


Lateral panel – HF result

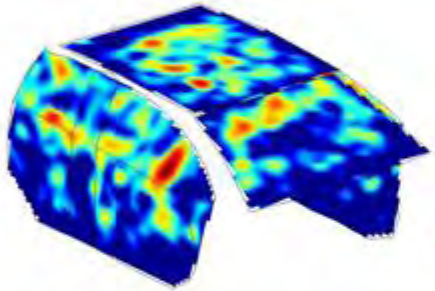
Even very faint defects will be identified!

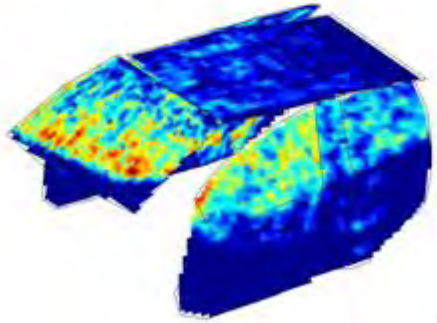
Automotive applications

Inside Vehicle Measurements

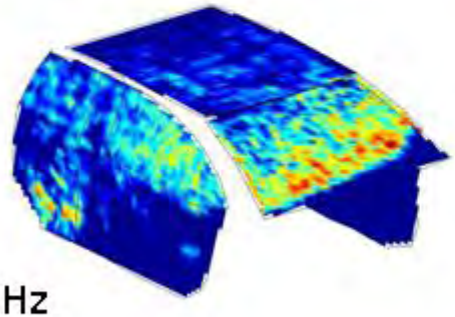


f1/3 = 630 Hz





f1/3 = 3150 Hz

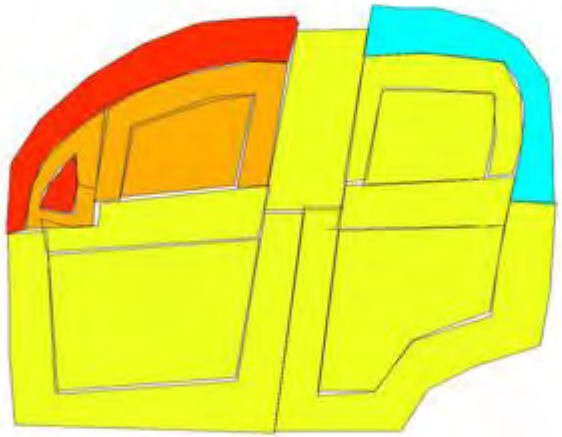


- 3D reconstruction of the acoustic weakness features along the car body
- Overall contribution to the inside vehicle disturbance

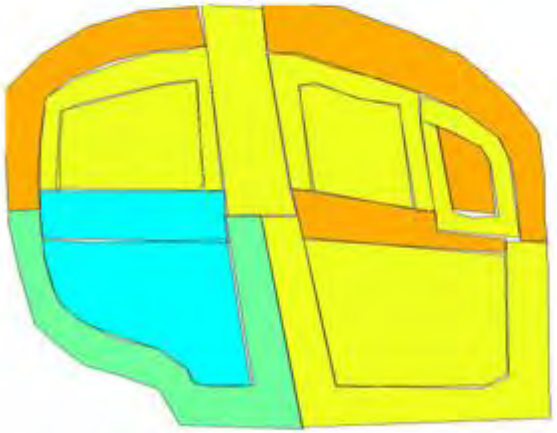
Complete car measurement within less than half a day!

Automotive applications

Inside Vehicle Measurements

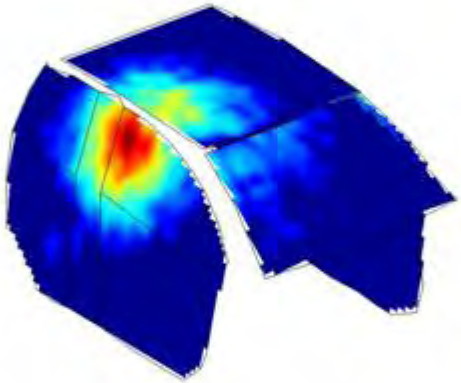


- Partial Loss Estimation
- Performance analysis on **Primary components**
- Help in the vehicle design process



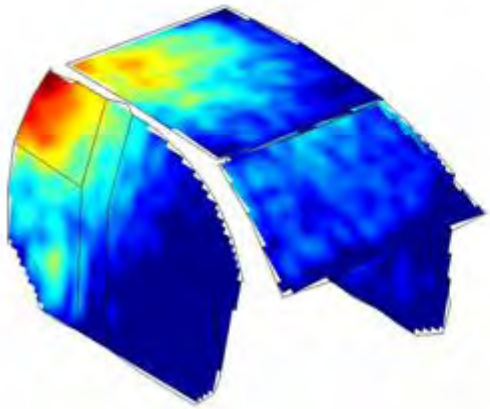
Automotive applications

Inside Vehicle Measurements



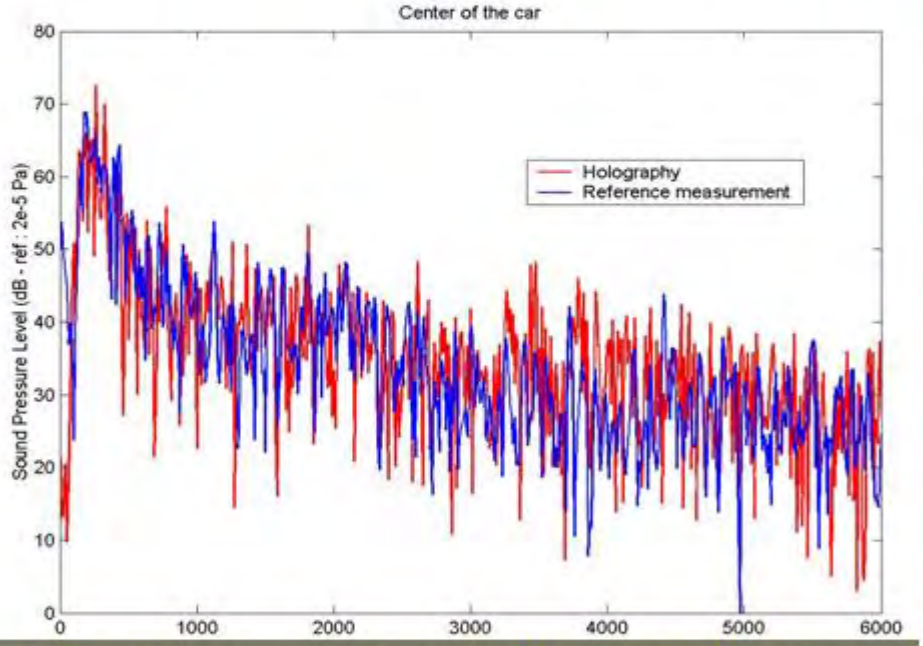
- Inside Acoustic Pressure Prediction
- Hear Contribution
- Possible future coupling to synthesis tools for audio analysis

EarVision™ concept

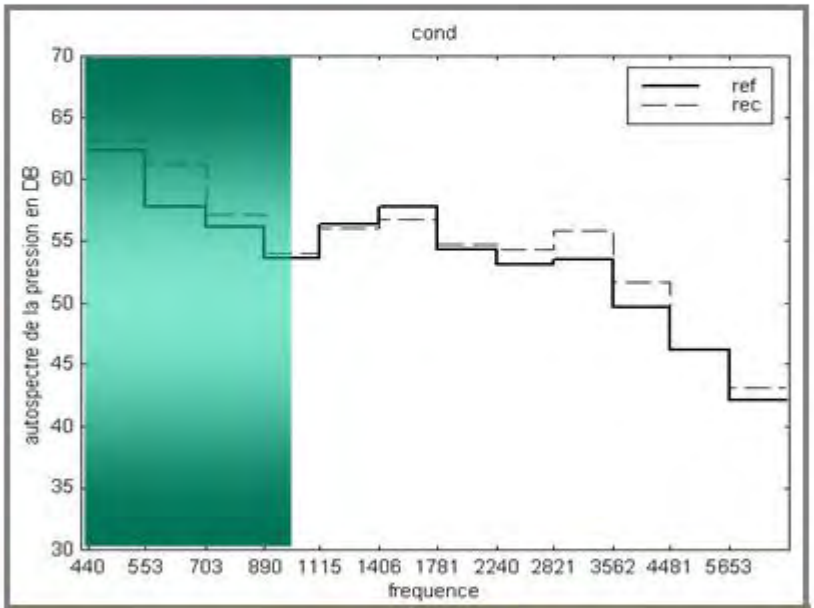


Automotive applications

Predicting acoustic levels inside vehicle



Acoustic pressure at car inside central location...



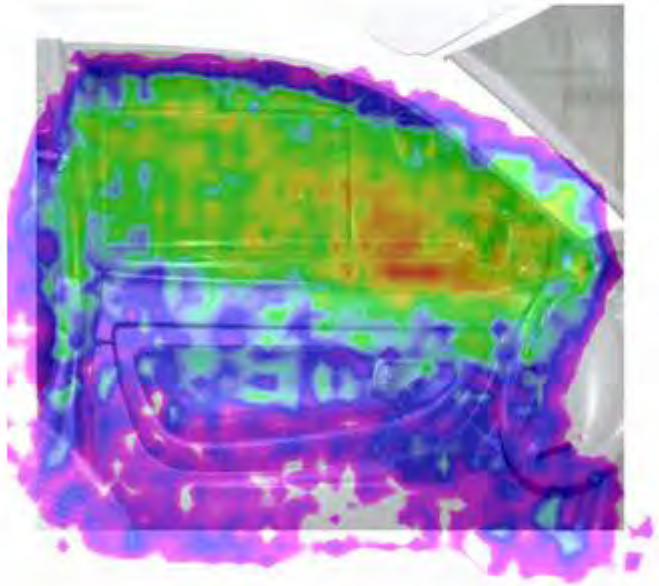
... or at driver's ear

Max. discrepancy ± 2dB using HIE & free space Green's function

Automotive applications: aeroacoustics

Wind tunnel Trials – inside measurements

- ✓ Car door analysis – driver side
  - o Typical 1/3rd octave band results

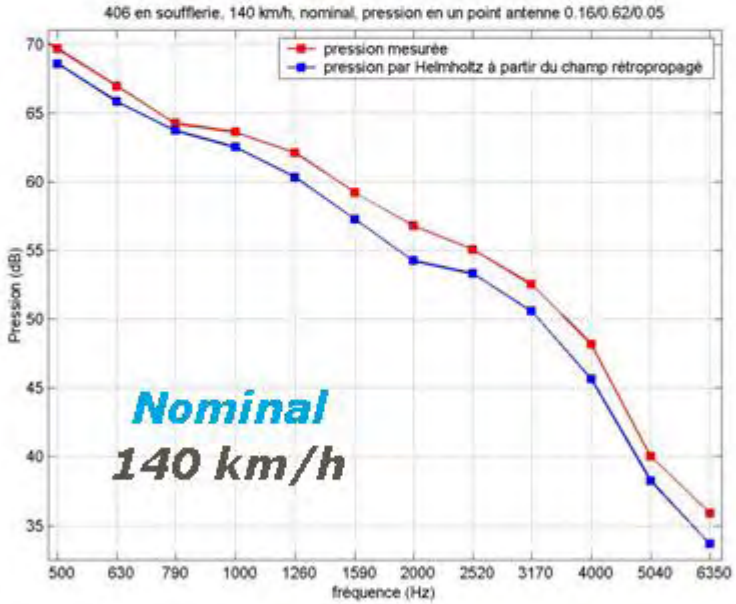


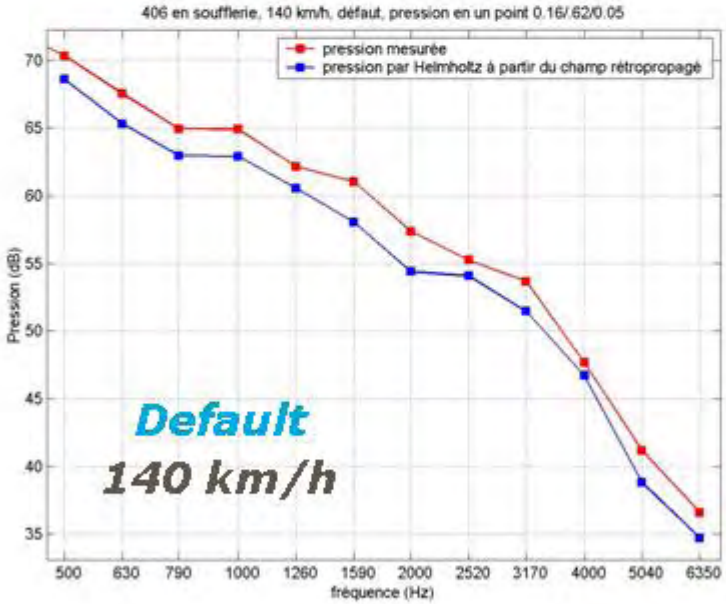
This result on-site within less than half an hour!

Automotive applications: aeroacoustics

❑ Acoustic pressure reconstruction from holography

- **red** : measured pressure at array location (selected microphone)
- **blue** : reconstructed pressure at same location using HIE**



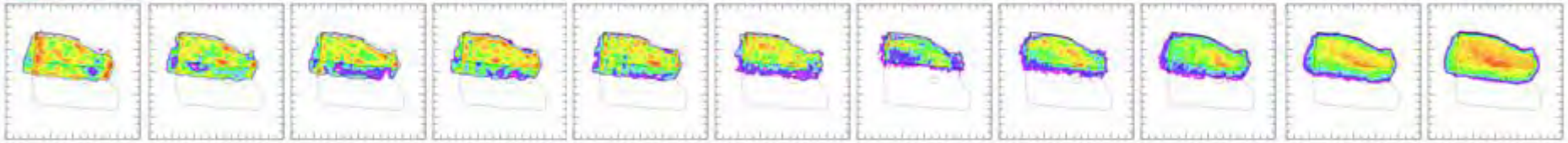


** *HIE = Helmholtz Integral Equation – free field Green function*

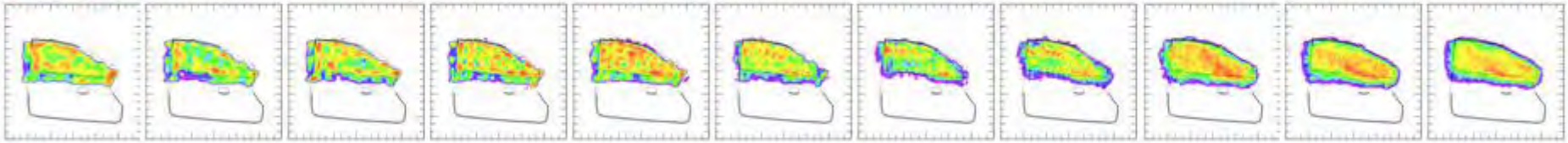
Automotive applications: aeroacoustics

- Holography maps – acoustic pressure levels in dB
  - ✓ Overall comparison – different speeds - all frequency ranges

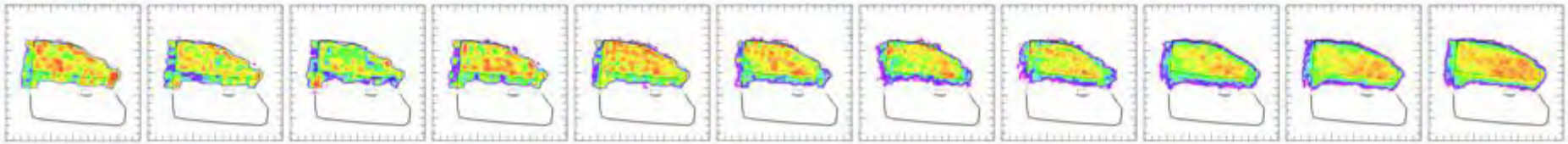
100 km/h



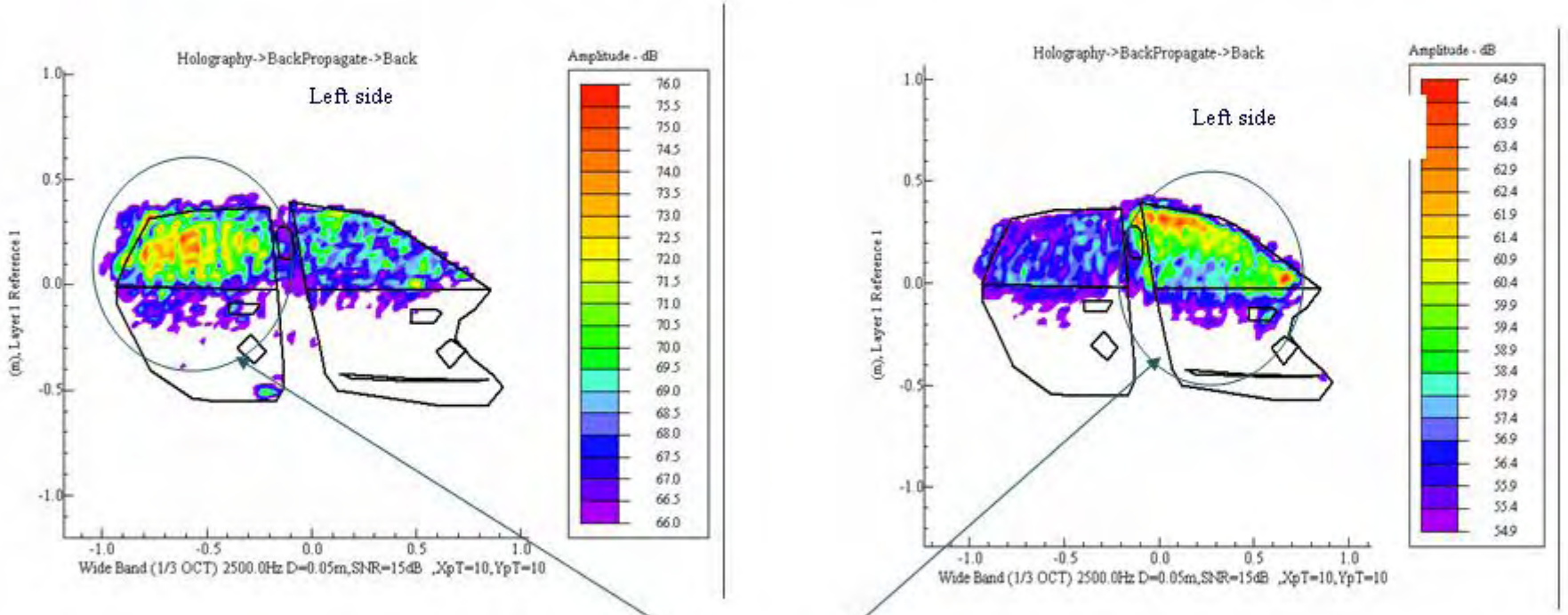
140 km/h



180 km/h



Automotive applications: RR/aeroacoustics

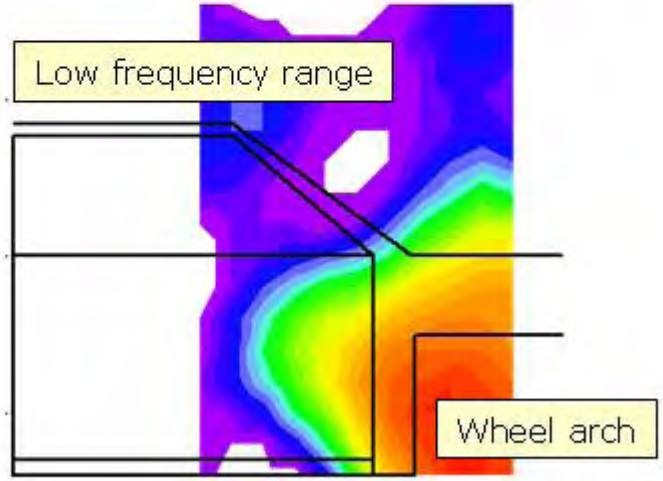


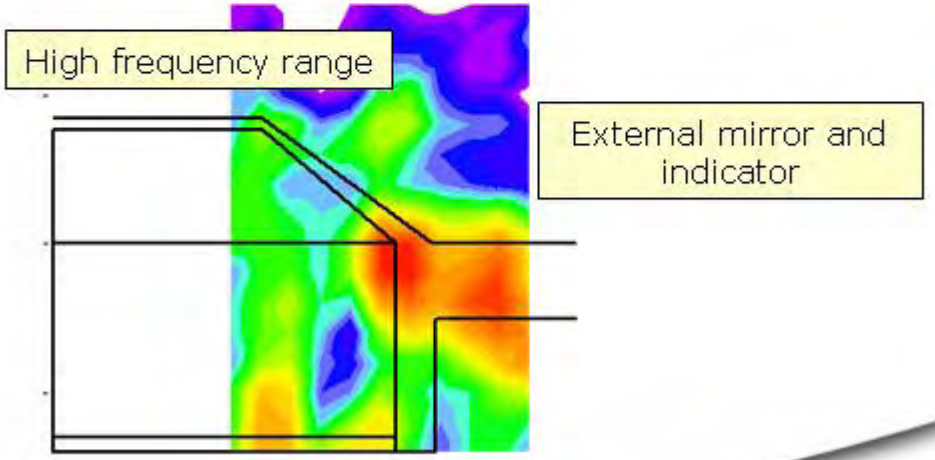
« Static » acoustic features obtained in diffused field are reverse when Wind Tunnel Aeroacoustic load is applied …

Automotive applications: aeroacoustics

Wind tunnel Trials – outside measurements

- **external** measurements in wind tunnel
- acoustic array out of wind flow
- back-propagation process in front of the lateral side

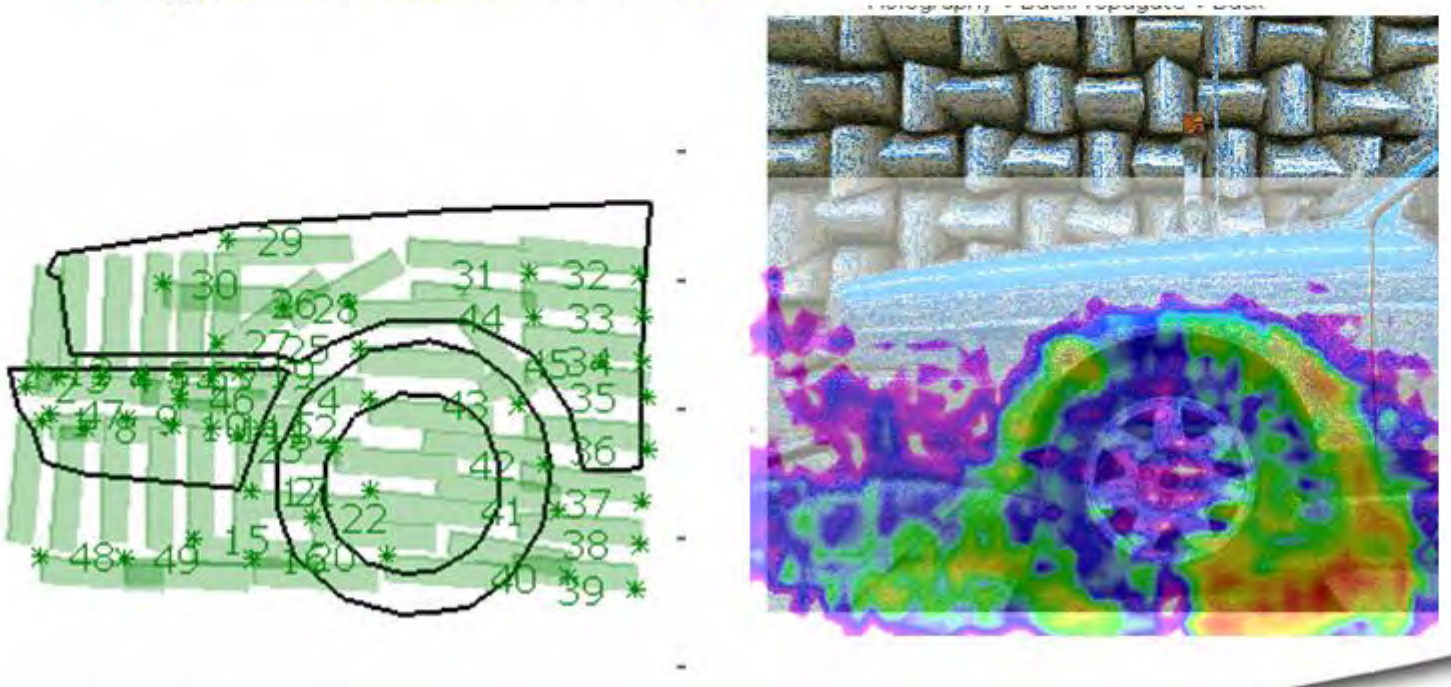




Automotive applications: radiated noise

Rolling test bench situation

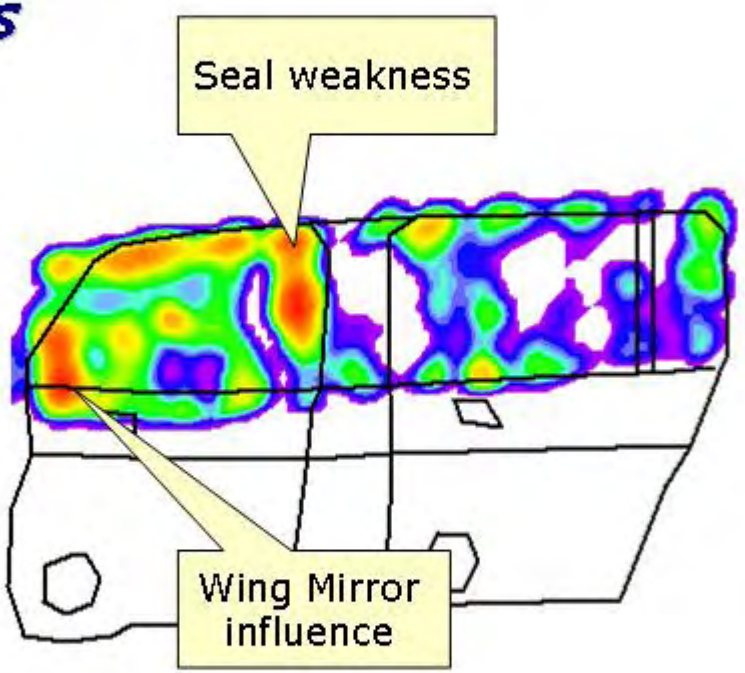
- ✓ Vehicle at 50 km/h – front driver side analysis
  - o Typical 1/3rd octave band results



Automotive applications: aeroacoustics

On Road Trials

- Inside Vehicle Measurements
- External acoustic « sources »
- Demonstration of the accurate localisation capability of dBVISION
- Short time of experimentation

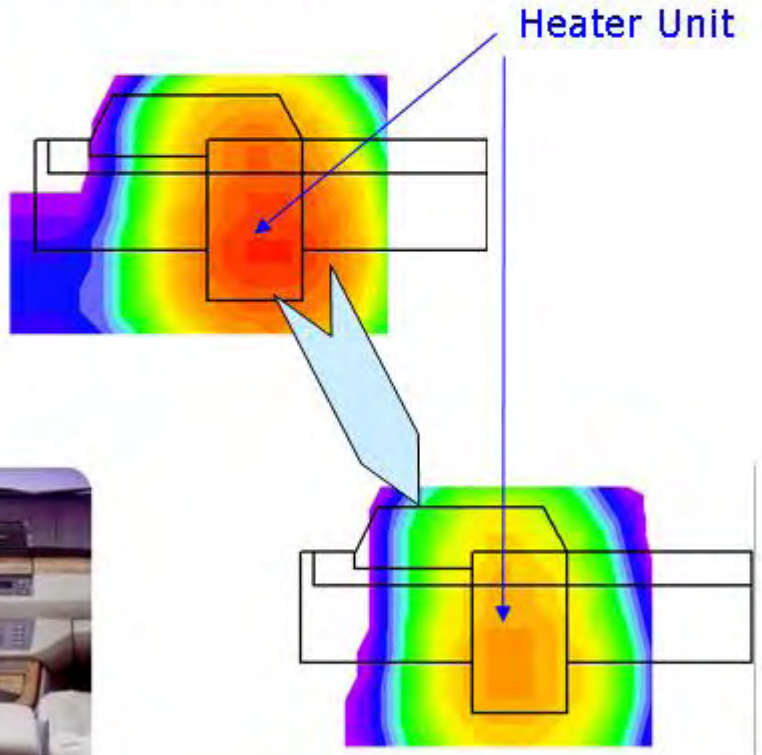


Hot spots localisation inside a passenger cell due to external aeroacoustic loads

Automotive applications: components

Dashboard Vibration Control

- Dashboard on vibration bench test
- Identification of the noisiest equipment (heater unit in the central part)
- Modification and immediate display for checking relevance

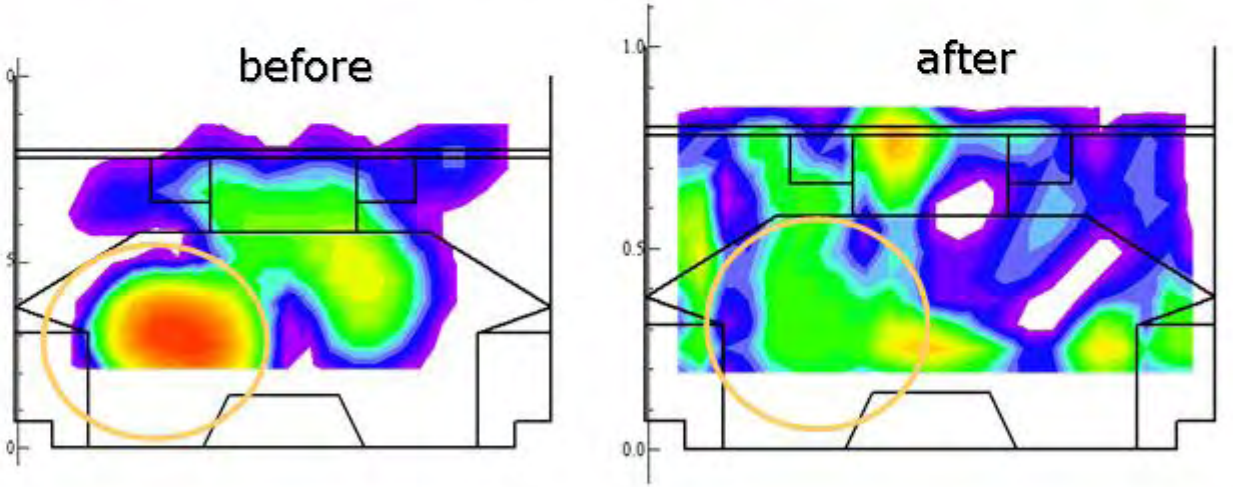


Automotive applications: components

Inside Vehicle Measurements

Front Panel Control

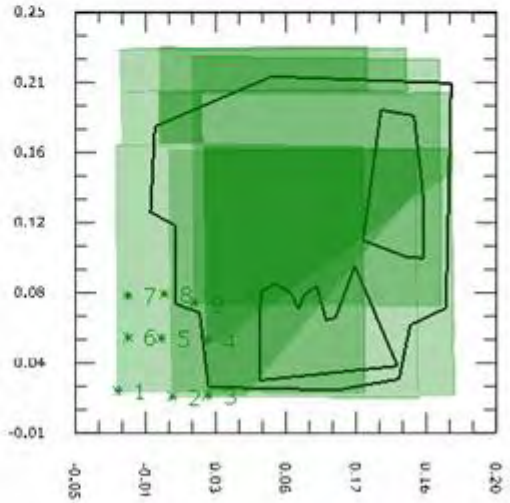
- Mechanical mount optimisation

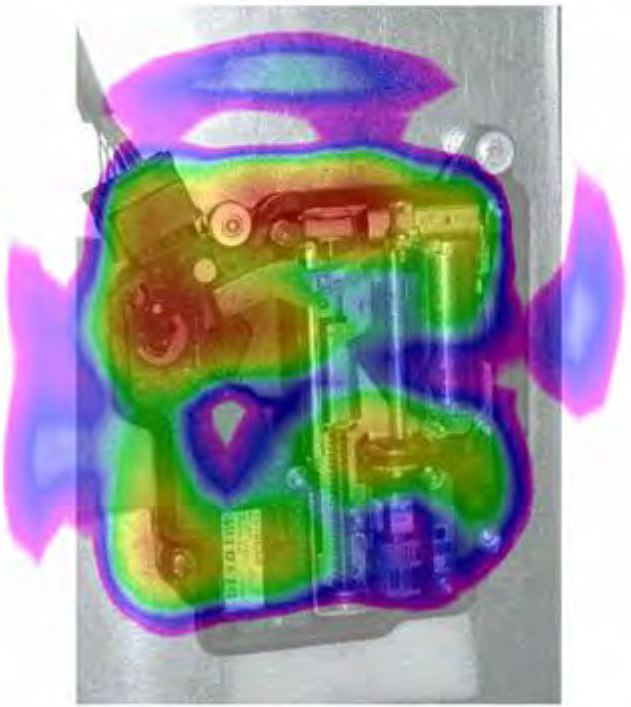


Automotive applications: components

Servomechanism

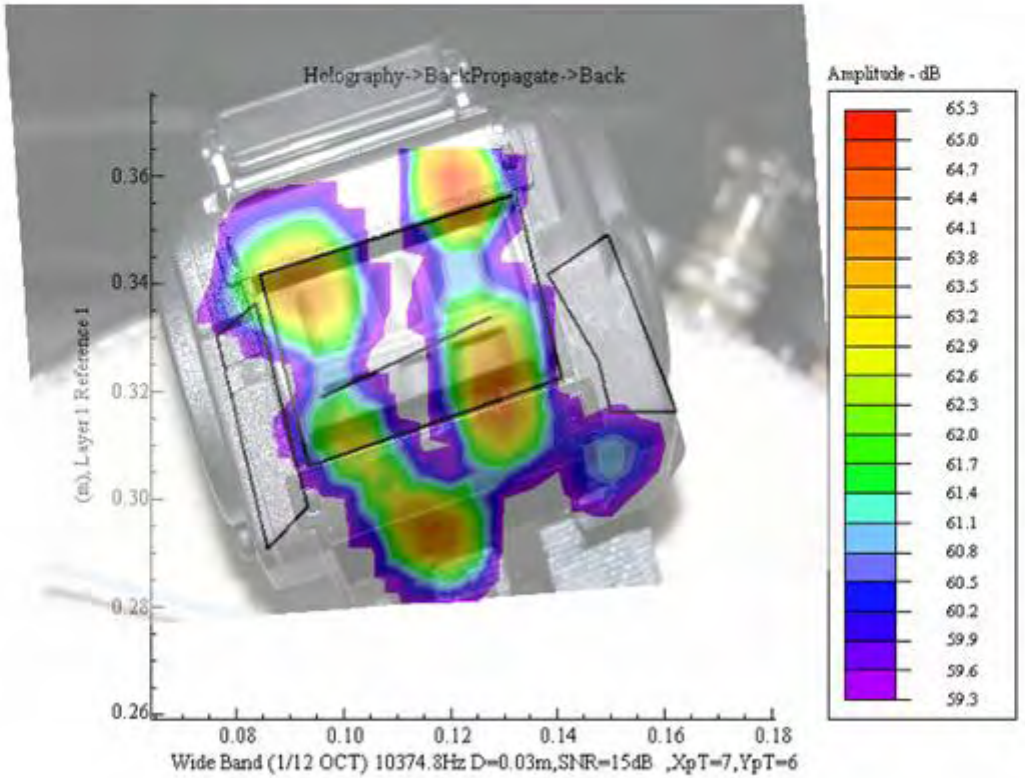
- ✓ Quasi transient situation
  - o Typical 1/3rd octave band results





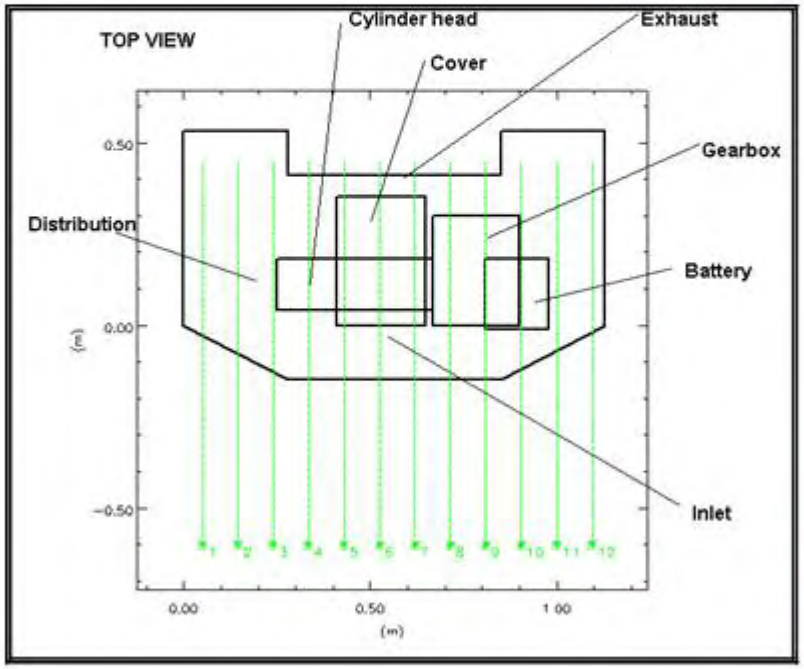
Automotive applications: components

Seat belt retractor



Automotive applications: engine

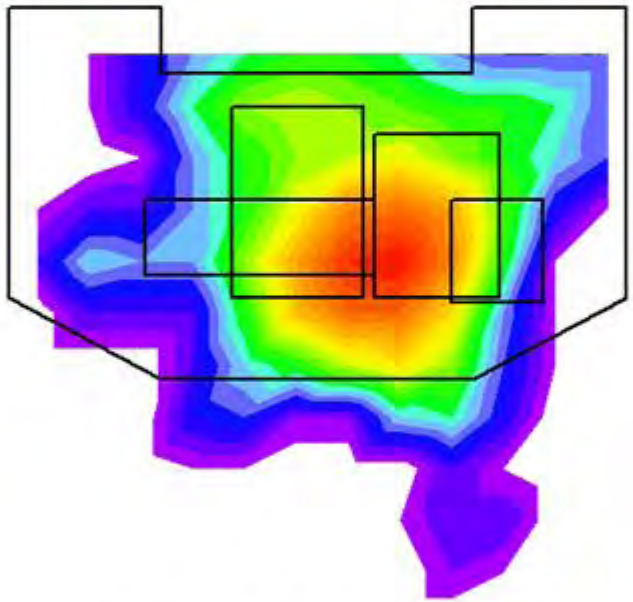
Car Engine Radiation



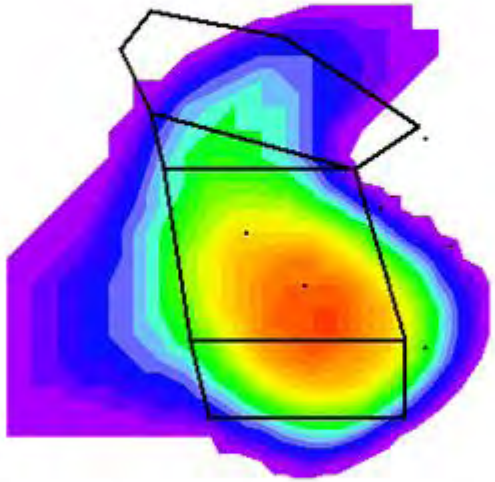
- car engine noise signature processing
- complete vehicle on rolling test bench
- noise source localisation and quantification
- evolution follow-up

Automotive applications: engine

Car Engine Radiation – first results late 1990's



Gear box/Engine



Crankshaft Pulley
(distribution face)

Automotive applications: engine

Source localisation on a running engine

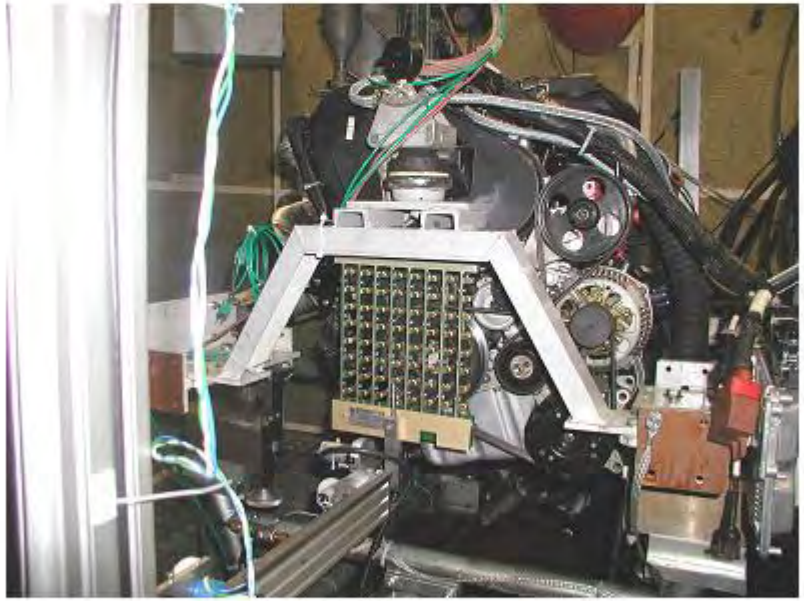
- Direct formulation:

$$p_m = \left[H^{-1}\right]\gamma_s$$

Tikhonov regularisation

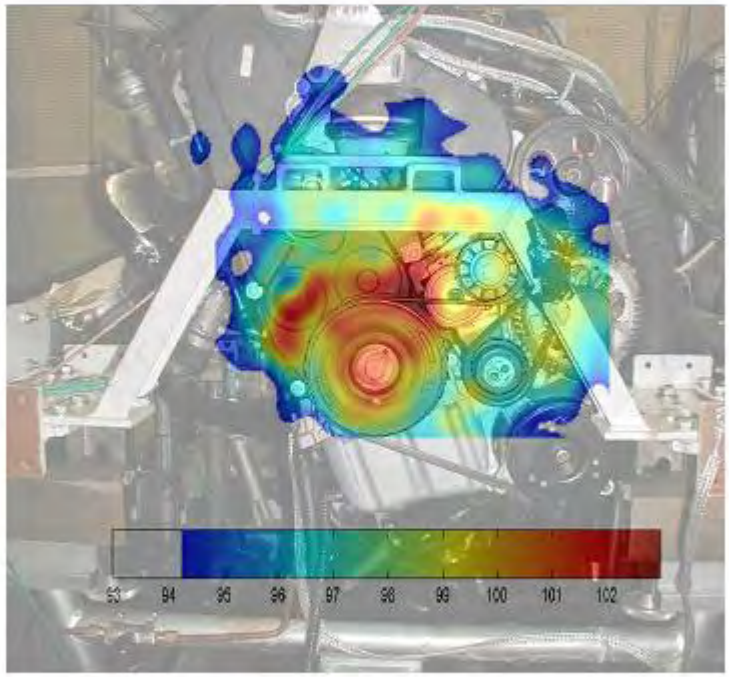
- Minimising the functional:

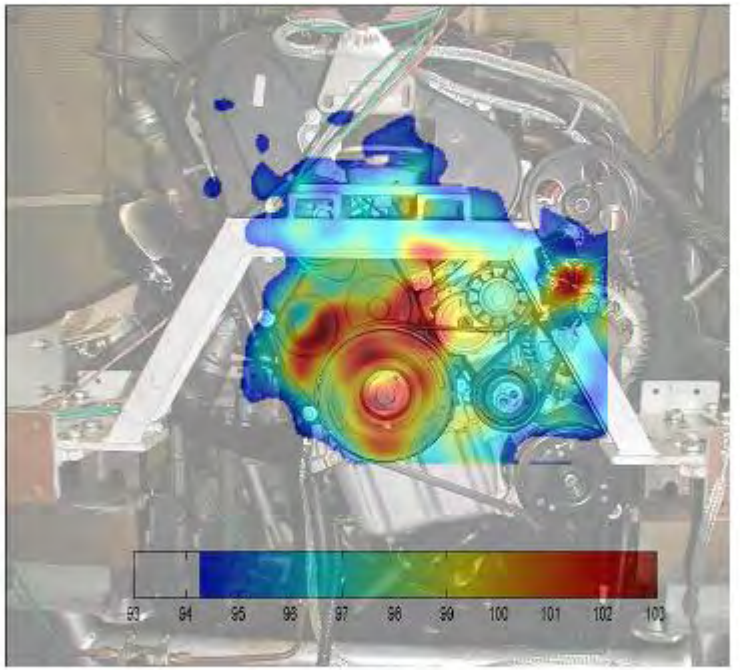
$$J_\alpha = \left\| \left[H\right]\gamma_s - p_m \right\|^2 + \alpha \left\| \gamma_s \right\|^2$$



Automotive applications: engine

Source localisation on a running engine

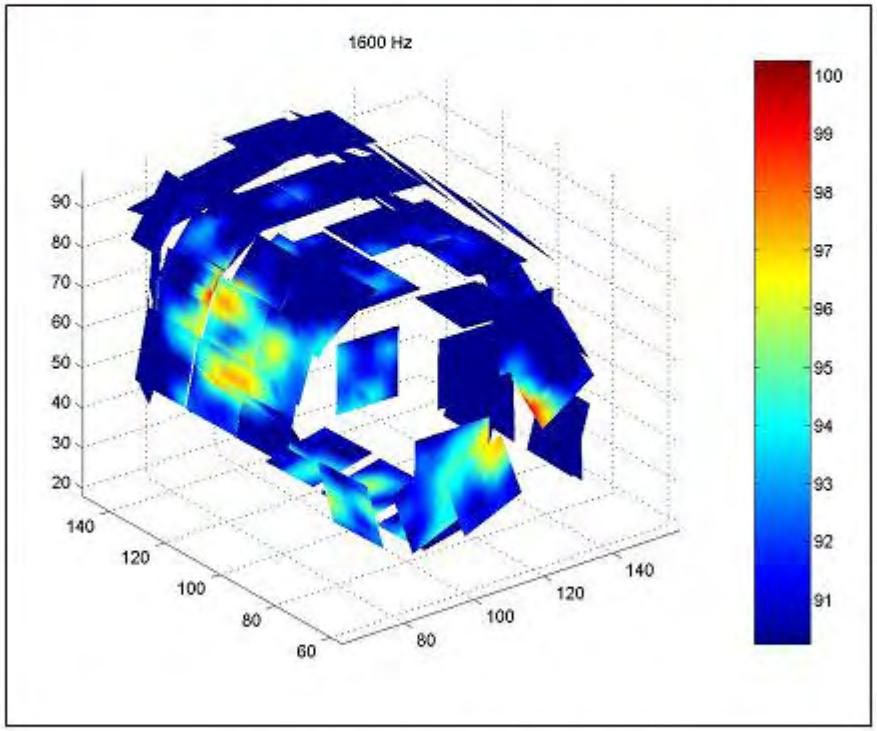




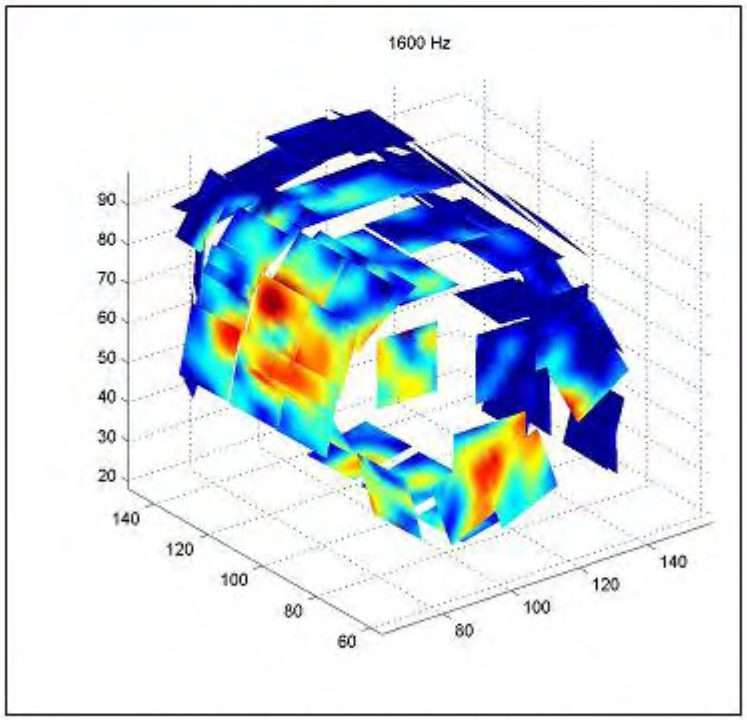
Comparing 2 configurations without/with default on the alternator device
(typical 1/3rd octave band result)

3D extensions

Source localisation on a running engine



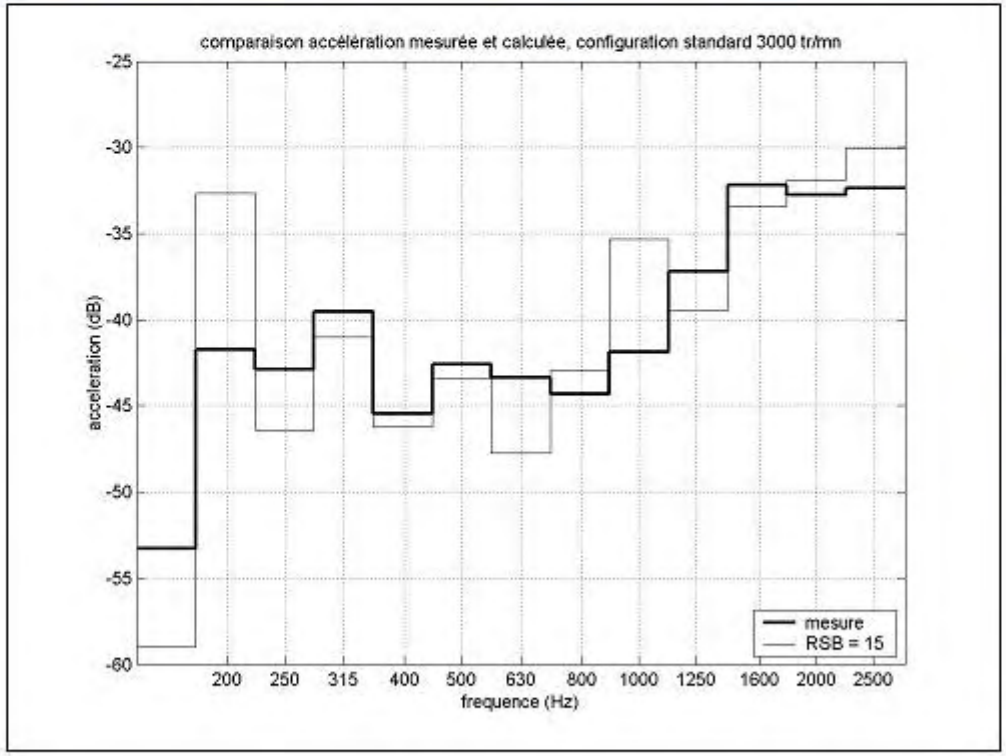
3000 tr/min 125 Nm



3000 tr/min 125 Nm
Combustion default

3D extensions

Source quantification: acceleration on the oil sump

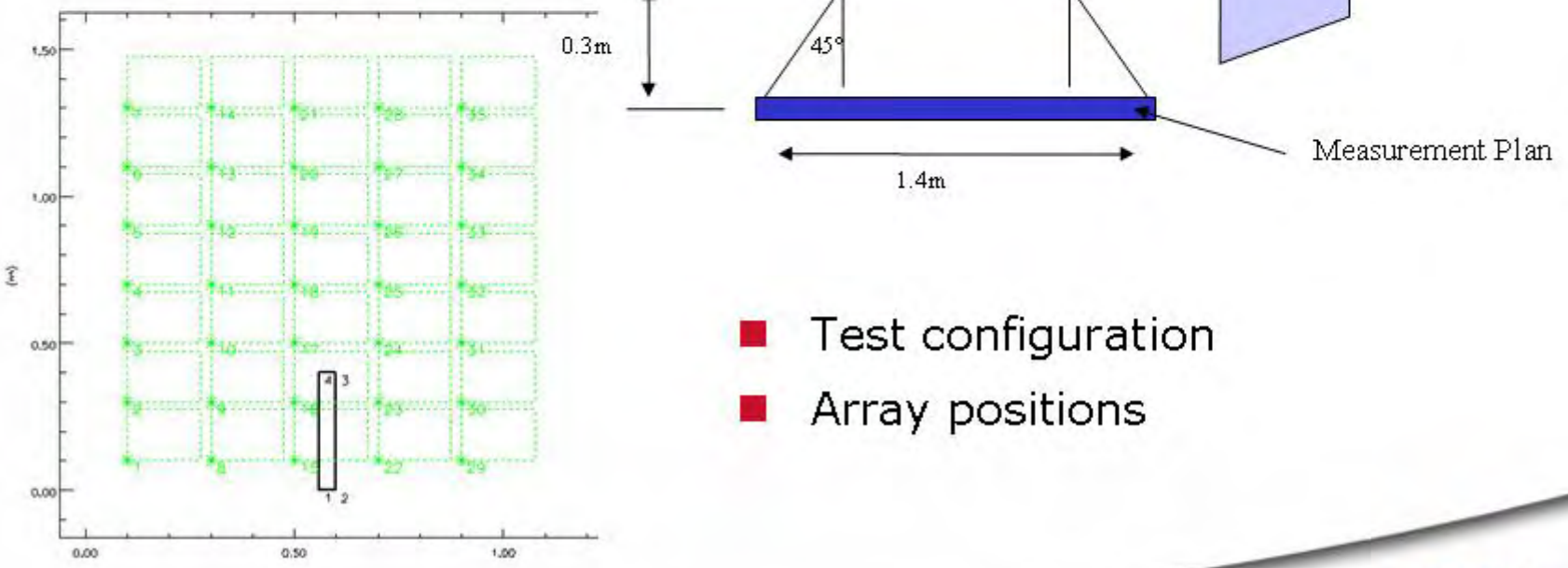


3000 tr/min 125 Nm

Comparison accelerometer measurement/prediction

Automotive applications: engine

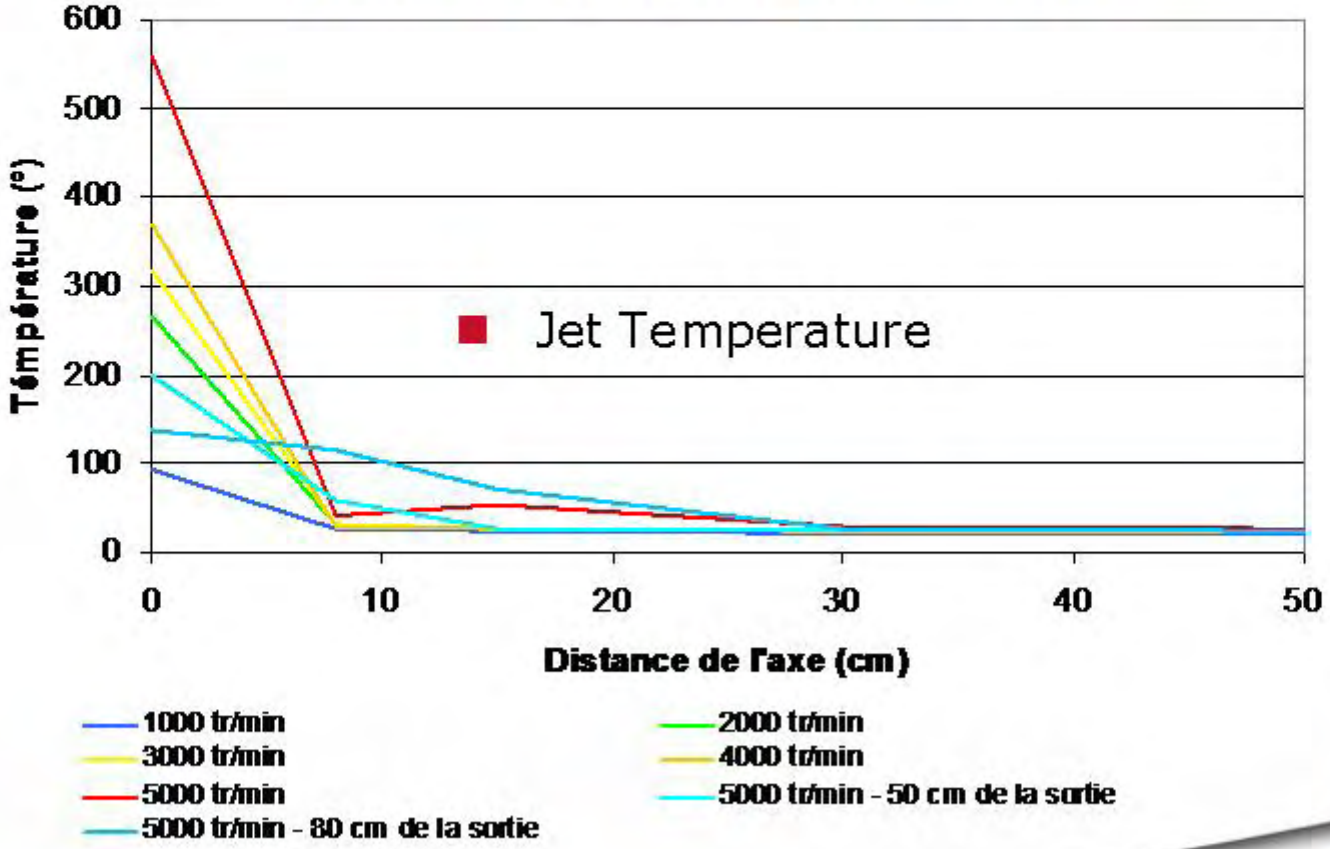
Exhaust Noise refinement



- Test configuration
- Array positions

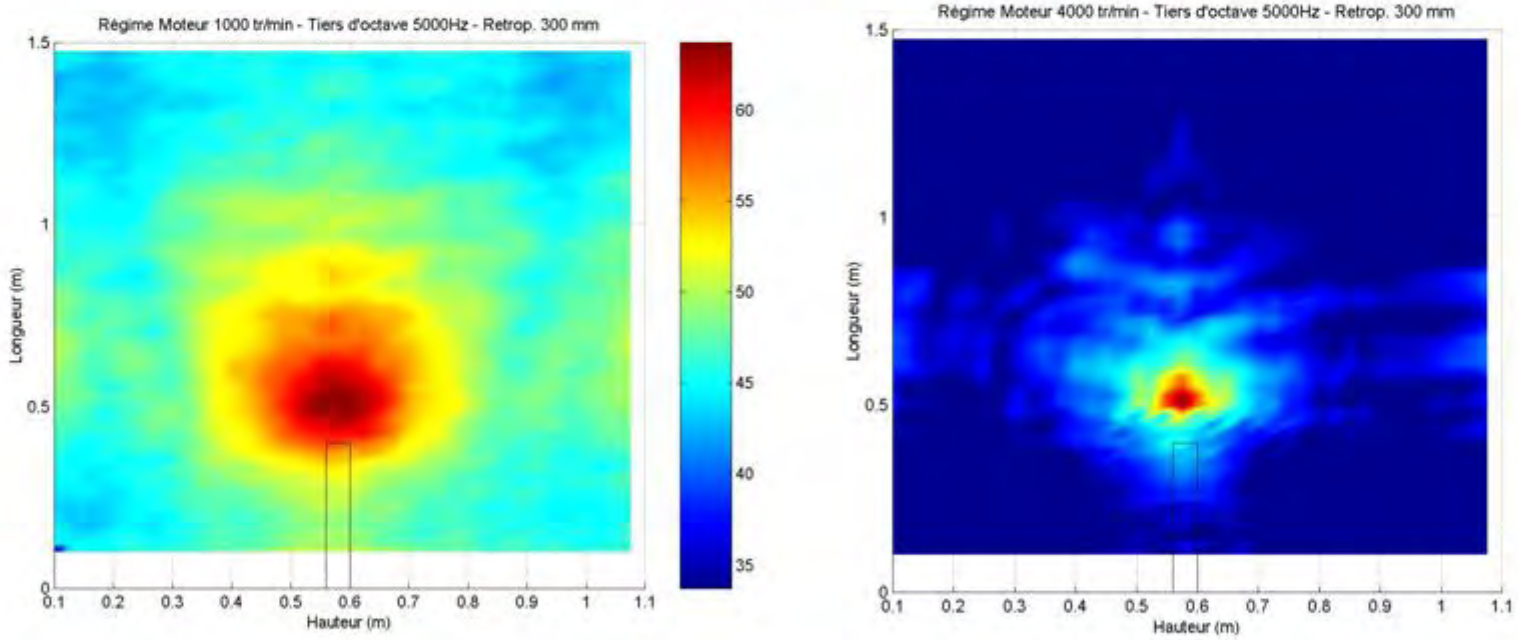
Automotive applications: engine

Exhaust Noise refinement



Automotive applications: engine

Exhaust Noise refinement

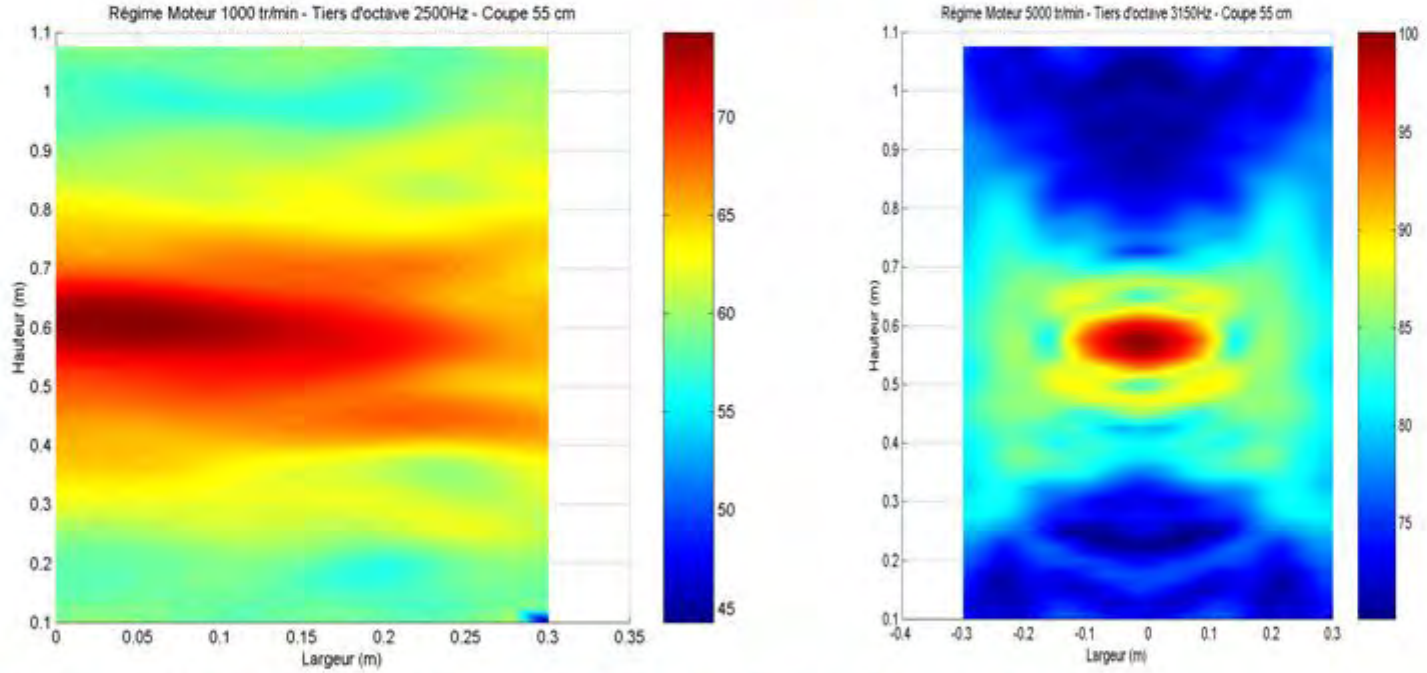


Intensity display within the exhaust jet parallel to the measurement plan:

- Left is LOW REGINE (1000 rpm) – Right is HIGHER REGIME (4000 rpm)

Automotive applications: engine

Exhaust Noise refinement

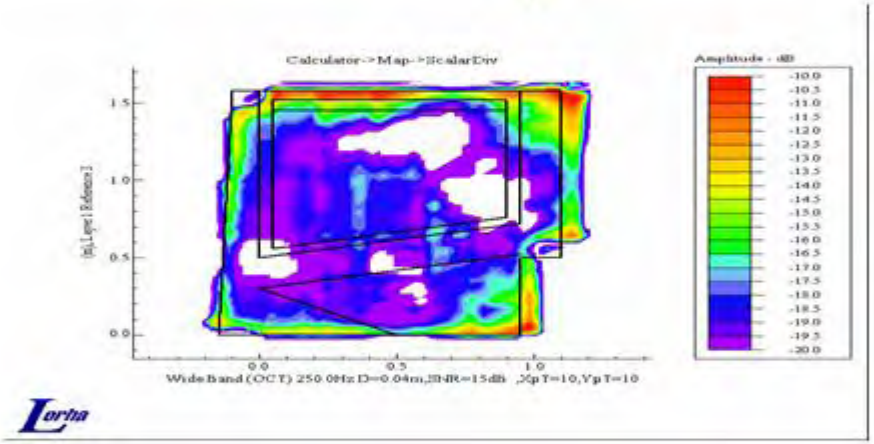


Acoustic pressure map perpendicular to the exhaust jet:

- Left is LOW REGINE (1000 rpm) – Right is HIGHER REGIME (5000 rpm)

Other industrial applications

Cabin noise at the operator location
Heavy material handling machine

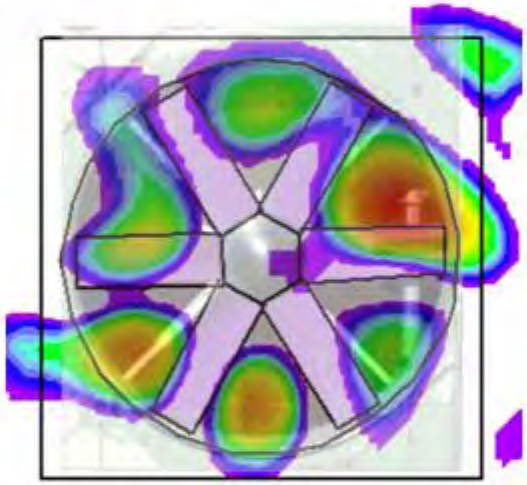


Most efficient use of information issued from holography measurements:

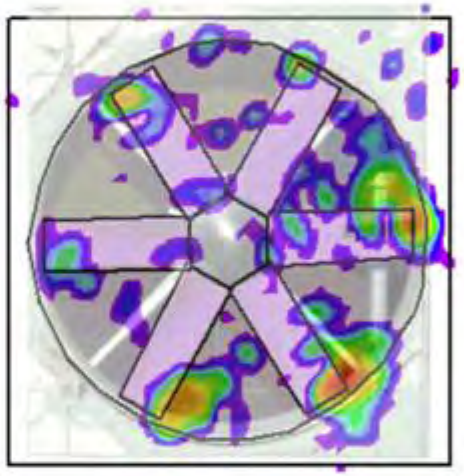
- One day of testing delivered all sensitive parts in terms of acoustical leaks
  → Recommendations for insulating material implementation
- Final results on modified cabin interior insulation: **15dB improvement !!**

Other industrial applications

Fan Noise: synchronous analysis...



1000 Hz



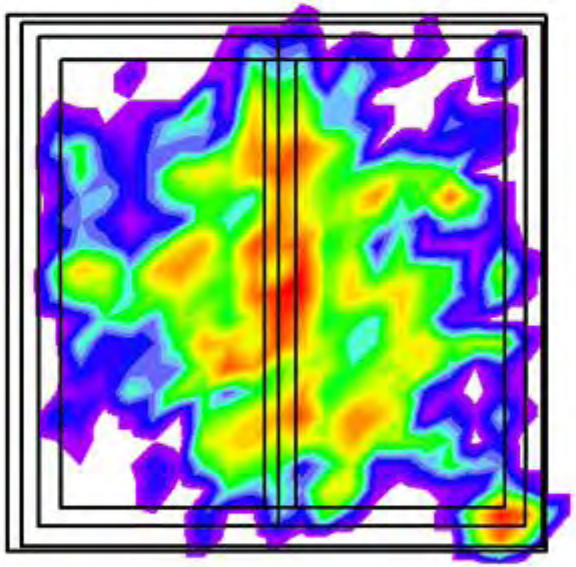
4800 Hz

Understanding of the **interactions** between the flow, the blades and the fixed part of the fan which contribute to the sound radiation:

- at low frequency: main noise sources located between blades and fixed elements in front of the fan
- at higher frequency: sources located at the blade trailing edge

Other industrial applications

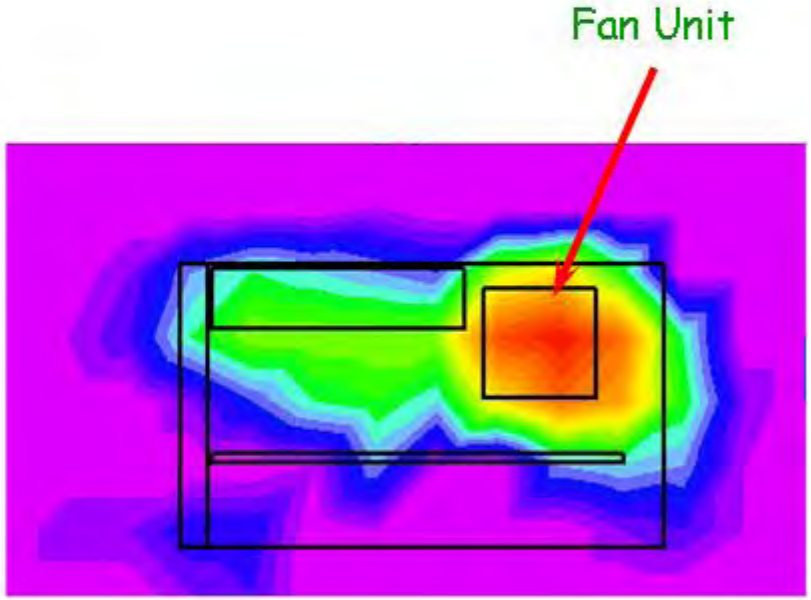
Building Window Acoustical Properties



1/3 octave 1600 Hz

Other industrial applications

Computer hardware analysis

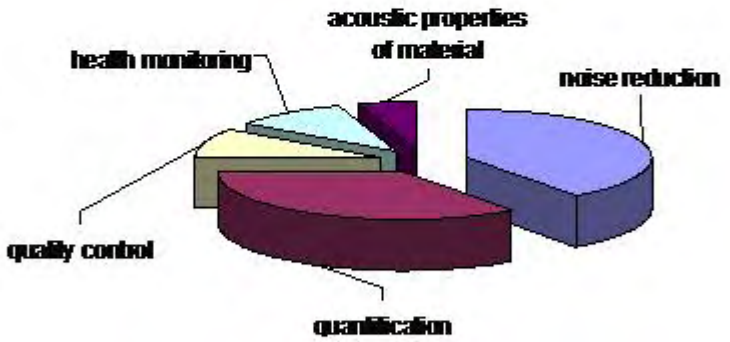


Localisation
and
identification
of the
disturbing components

Application domains

NAH fields of investigation

- noise reduction
- quantification of noise radiation
- quality control
- health monitoring
- acoustic properties of materials



Application domains

Noise reduction

- ✓ ***understand*** the radiated sound of every mechanism
- ✓ perform first a ***noise diagnostic***
- ✓ ***localise*** the main noisy sources
- ✓ evaluate the incidence of a noise reduction program using LORHA ***simulation*** capabilities

Quantification of noise radiation

- ✓ complete the noise diagnostic
- ✓ ***quantify*** the overall sound radiated by the tested equipment
- ✓ evaluate the relative impact of each source on the global radiated acoustic power (***noise ranking*** capability)

Application domains

Quality Control

- ✓ declare the tested equipment as "***good***" or "***bad***" referring to standard criteria (acoustic power, maximum pressure level, …)

Health Monitoring

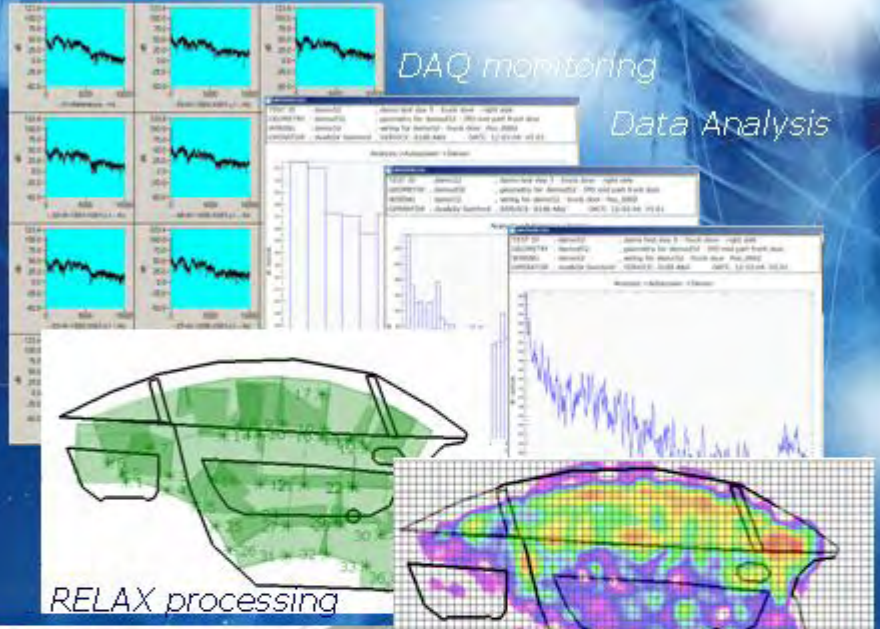
- ✓ solve usual problems involving ***a long use*** of a machine
- ✓ ***control*** the evolution of the sound radiated by the surveyed machine

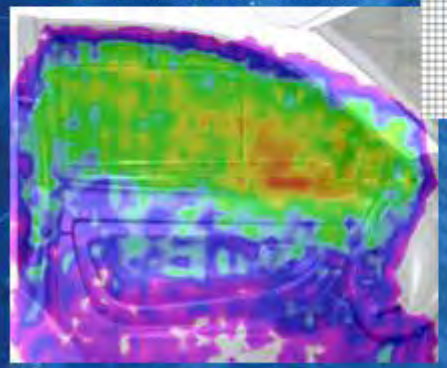
Acoustic Properties of Materials

- ✓ analyse the ***acoustic performance*** of materials such as acoustic isolation
- ✓ compute relevant index such as ***transmission loss*** factor

Acoustical Imaging Techniques & Holography

dB VISION





Final Output
Your holography maps on site!

The complete system at one glance !

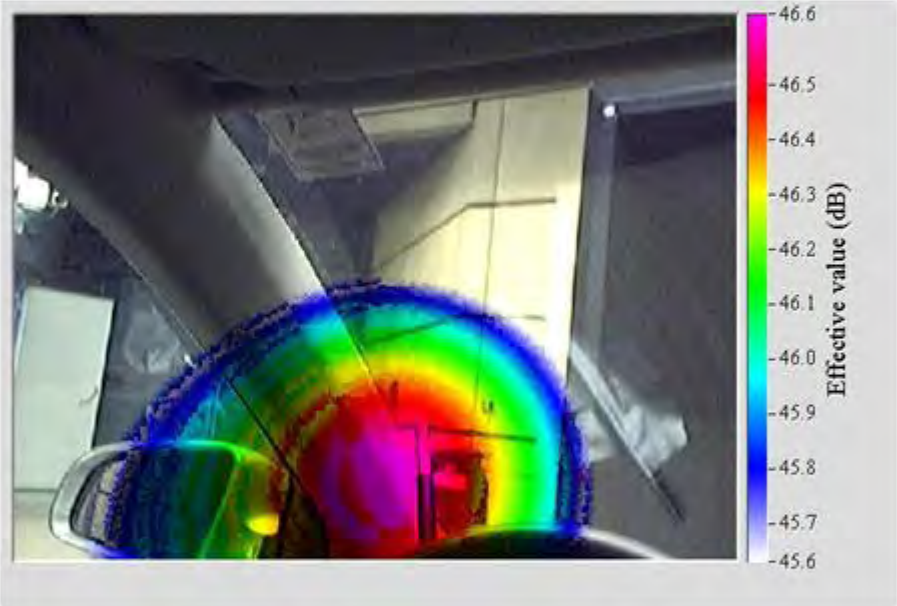
01dB METRAVIB

Conclusions

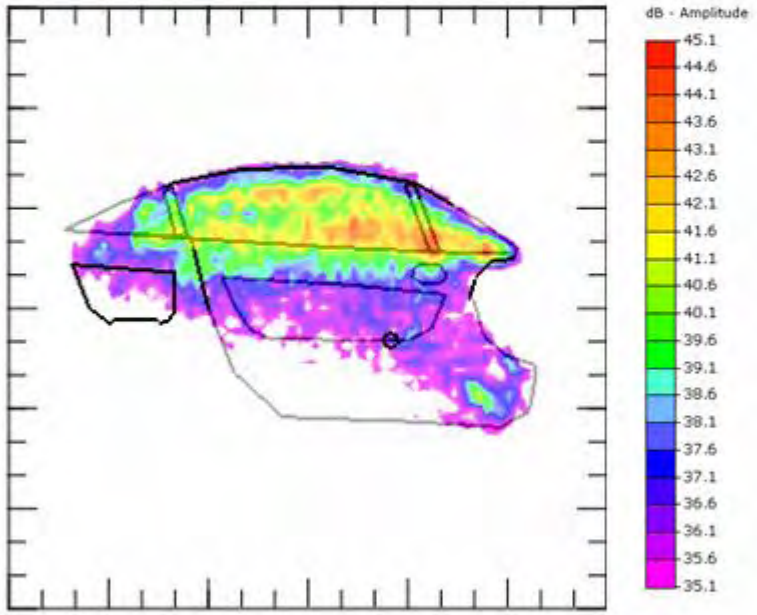
- Relevance of the NAH approach for industrial applications
  - ✓ Within the design engineering process for:
    - o both target setting and cascading help fixing targets
    - o Sketch first scenarios
    - o Benchmark competing solutions
    - o Compare and select best component on in situ criteria
  - ✓ Within the diagnosis/comparison/optimization loop providing:
    - o Detailed localization of noise sources and acoustic weakness points
    - o Knowledge of the acoustic energy distribution on selected areas
    - o Simulation of the energy radiated by such components (source ranking)
    - o Estimates of the incidence of local modifications
  - ✓ As an operational and productive tool offering:
    - o Operating realistic measurement positions
    - o Improving operator's productivity
    - o Enhancing results reliability through relevant indicators during test

Conclusions

- Most accurate NAH results vs. beamforming!



*Beamforming Image with a **1 dB scale***



*Holography map with a **10 dB scale !***

Quick "comparison" between Beamforming and Acoustical Holography inside vehicle