Acoustic porous solutions for aircraft (exterior and interior noises)

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return on innovation

Outline

- Acoustic porous solutions for exterior noise
  - Context
  - Classical acoustic liners
  - Measurement techniques with grazing flow
  - Influence of main parameters
  - Other concepts of liners
- Acoustic porous solutions for interior noise
  - Context
  - Classical and optimised Trim panels

….Through experiments and simulations led in Onera in conjunction with research and academic institutions

Acoustic porous solutions for exterior noise

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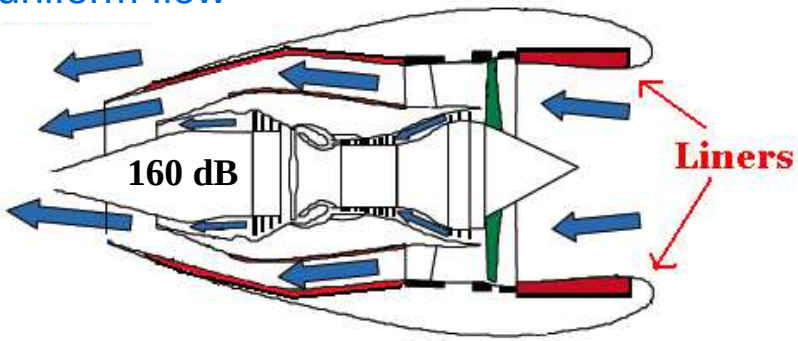
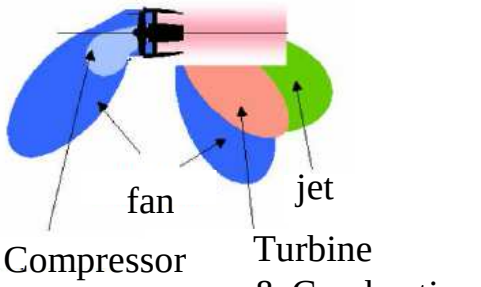
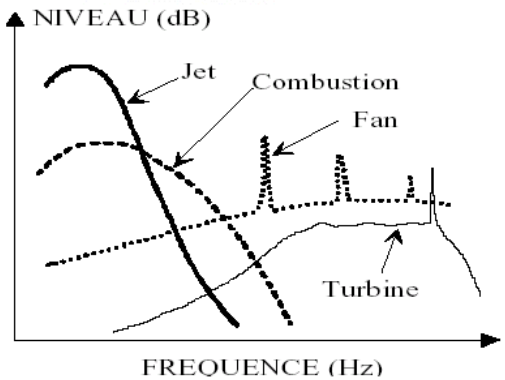
Context

Using of liners in nacelle aircraft engine
to reduce fan, turbine and combustion noises

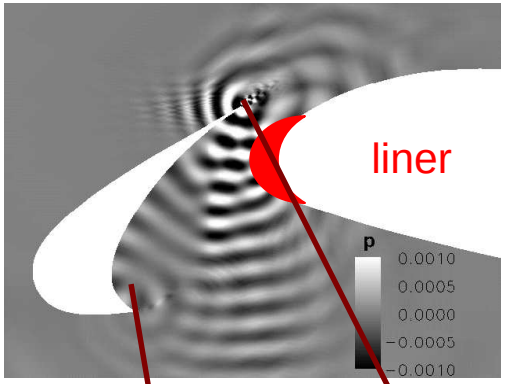
Non uniform flow

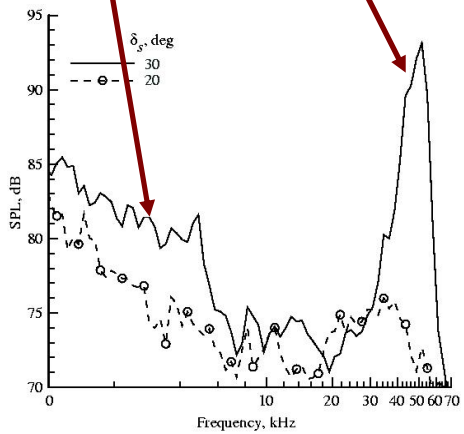






Using of liners in wing leading edge
to reduce interaction noise

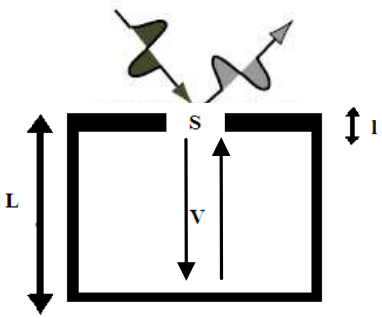




Acoustic Liners

- **Locally reacting behavior**
  - Model of surface impedance / Absorption in a narrow frequency band

- Porous layer (resistive) above cavity (reactive)

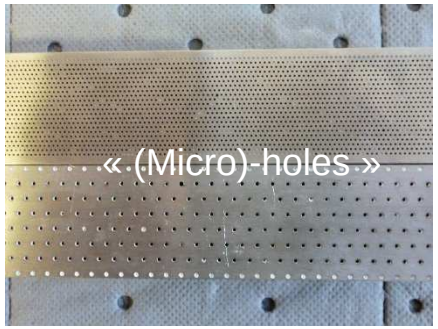


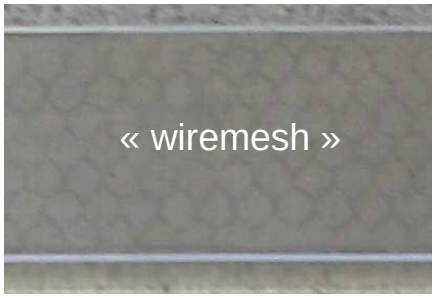
- Porous layer with
  - low specific resistance
  - high "*l/d*" (sheet thickness / hole diameter)
  - small holes
  - low porosity

- Honeycomb cells filled (or not) with porous material

5

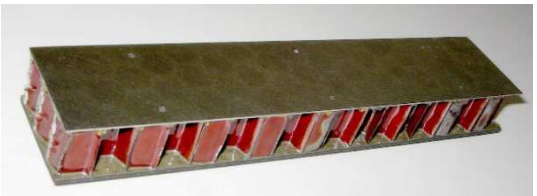
Samples of liners



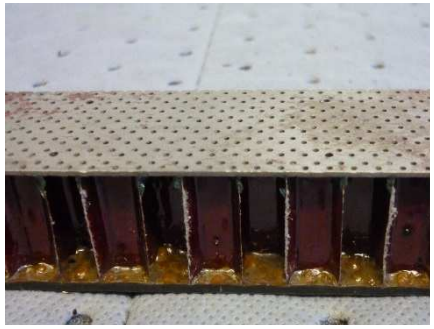


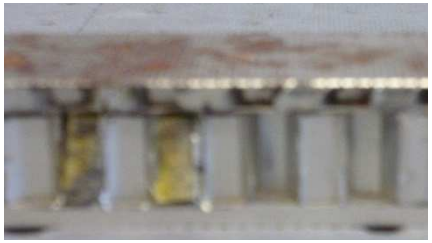
Resistive layers

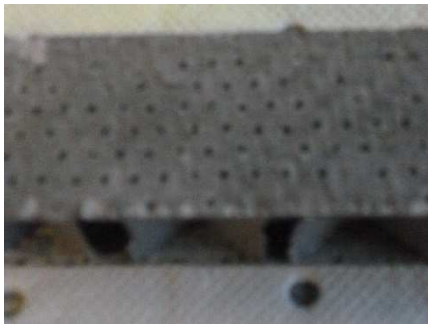
SDOF



2DOF





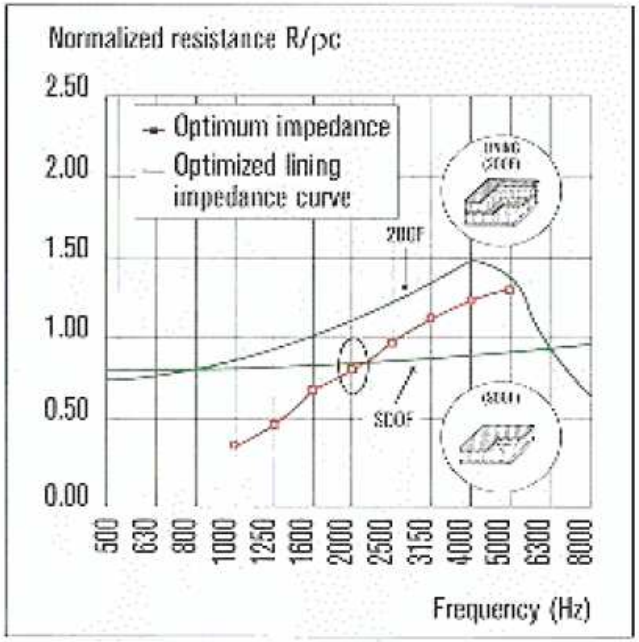


Honeycomb cells
with « drain » holes or
filled with porous material

Industrial requirements for engine noise

- Acoustic behaviour:
  - Reduction of Acoustic power associated to a specific liner surface
  - Optimal impedance on a given frequency range
- Aerodynamic behaviour:
  - Negligible impact
- Weight: max 8kg/m²
- Temp.: max 600-650 °C
- Mach: 0.5-0.6
- Fatigue strength, vibration, thermal cycle, thermal gradient, fire, drainage,

100000 – 200000 h

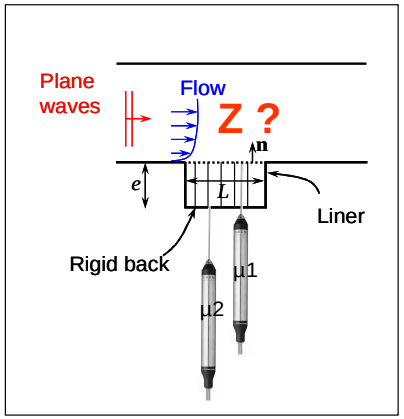


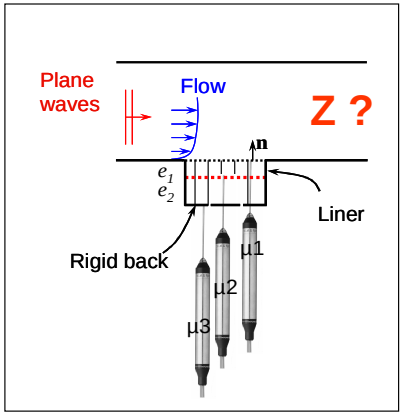
(Julliard, SNECMA)

Area	Air inlet	Cold duct downstream	Hot nozzle	Hot plug duct
Max (mm)	50	20-30	15	200
Impedance	R/ρc: 2 to 3 X/ρc: -0.5 to -1	R/ρc:1 to 1.5 X/ρc: 0 to -0.6	R/ρc:1 to 2 X/ρc: 0 to -0.5	R/ρc:0.5 to 1.5 X/ρc: 0 to -0.3

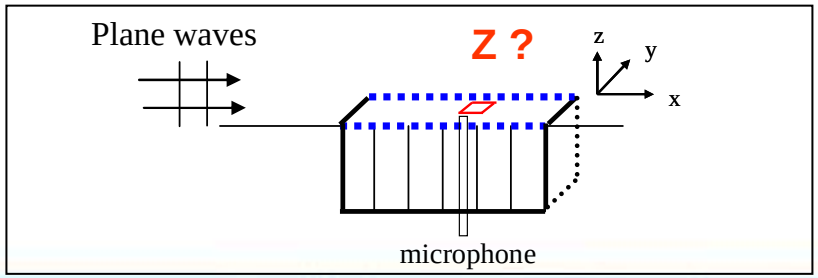
Liner impedance measurements with grazing flow

”In-situ” measurement method for SDOF or 2DOF
(Dean 1974, Onera)

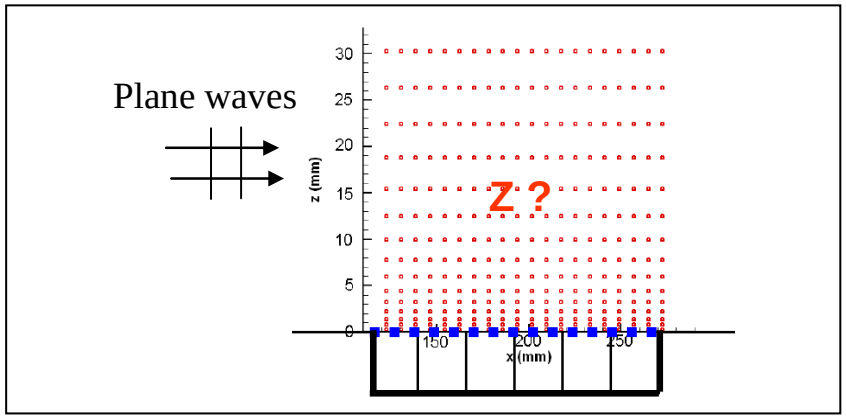




” Combined LDV-microphone ” method
(Onera, Nennig et al. 2009)



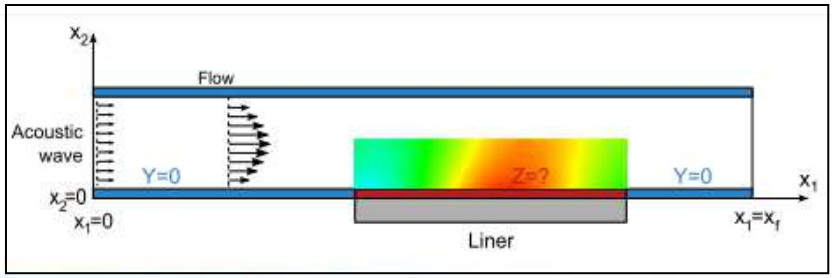
LDV method
(Onera, Nennig et al. 2009)



Acoustic impedance by direct computation *(Lidoine et al. 2007, Roche 2011, Zhang & Bodony 2011)*

Acoustic impedance by inverse method (eduction method)

(Watson & Jones 1996 - 2010, Primus et al. 2013)



Liner impedance measurements with grazing flow

”In-situ” measurement method for SDOF or 2DOF
(Dean 1974, Onera)

$$\frac{z_n}{\rho c} = -\frac{i}{\sin(ke)}\frac{p_1}{p_2} \qquad \text{(SDOF)}$$

$$\frac{z_n}{\rho c} = -\frac{i\ p_1}{\sin(ke_1)\ p_2 + \cos(ke_1)\sin(ke_2)\ p_3} \qquad \text{(2DOF)}$$

LDV method
(Onera, Nennig et al. 2009)

$$Z(z_i) = mean\left(\frac{P'(z_i)}{u'(z_i).\vec{n}}\right)$$

With Galbrun / Euler equations

” Combined LDV-microphone ” method
(Onera, Nennig et al. 2009)

$$Z = mean\left(\frac{P_{microphone}}{\bar{u}'_{LDV}.\vec{n}}\right)$$

Acoustic impedance by direct computation *(Lidoine et al. 2007, Roche 2011, Zhang & Bodony 2011)*

Acoustic impedance by inverse method (eduction method)

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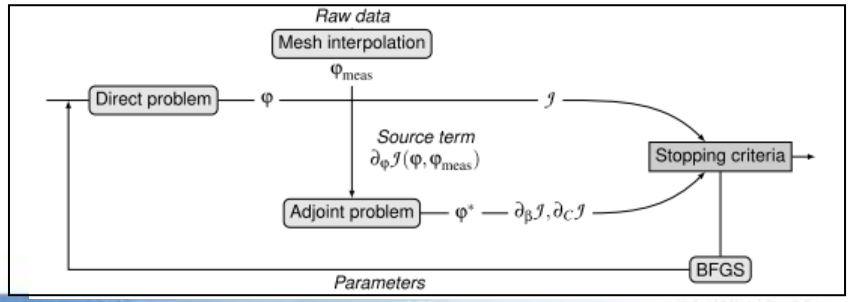
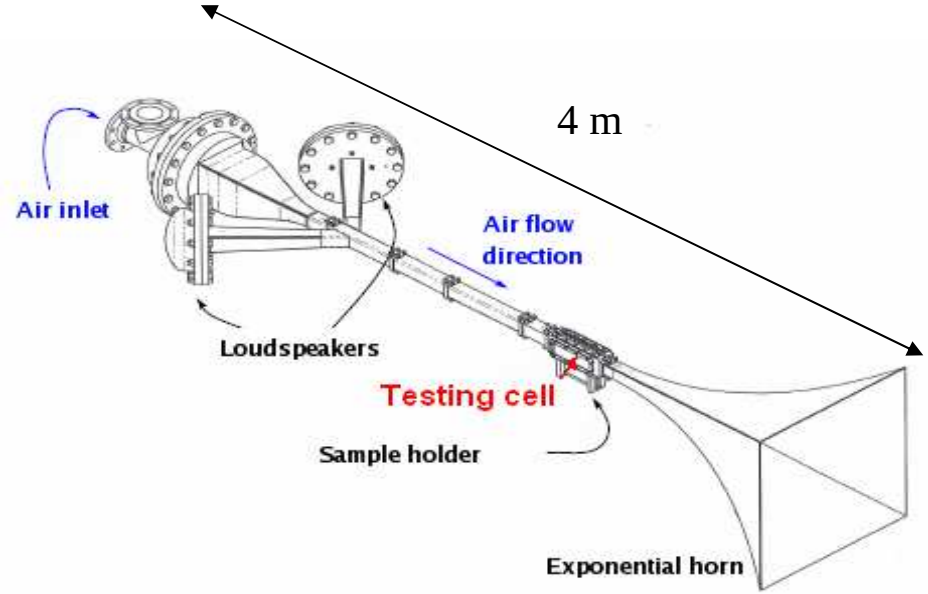
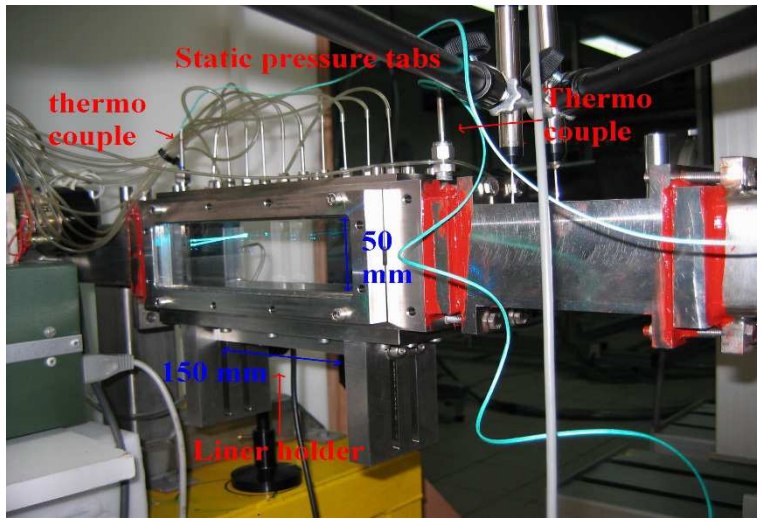
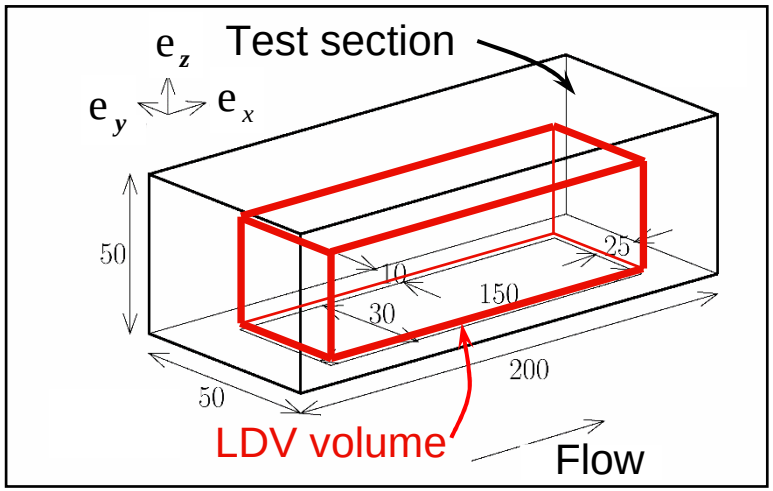


Onera Aero-thermo-acoustic bench (B2A)







Characteristics :

- regulated in flow-rate (Mach < 0.5)
  and in temperature (< 570 K)
- acoustic excitation up to 5000 Hz
  * planes waves: 300 to 3000 Hz
  •pressure level ~140 dB
- 2C-LDV measurements

LDV Measurement in B2A / exploitation / Galbrun's theoretical propagation model

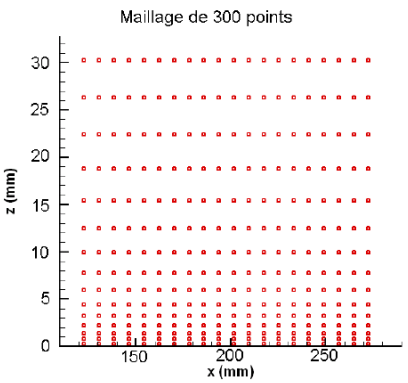
Signal processing

$$\begin{cases} V_x^{ref}\dfrac{\partial \xi_x}{\partial x} + i\omega\xi_x = \upsilon'_x - \dfrac{\partial V_x^{ref}}{\partial z}\xi_z \\ V_x^{ref}\dfrac{\partial \xi_z}{\partial x} + i\omega\xi_z = \upsilon'_z \end{cases}$$

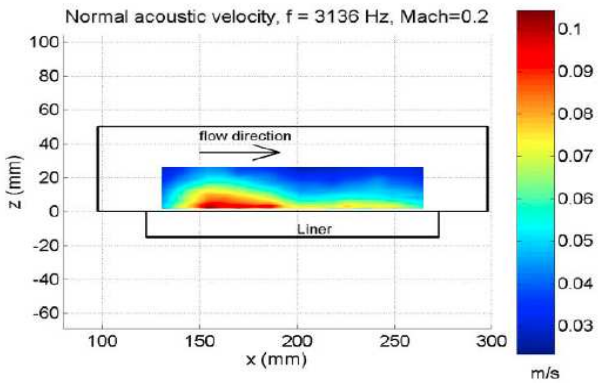
$$p' = -\rho^{ref} c^{ref^2} div\xi - \frac{dp^{ref}}{dx}\xi_x$$

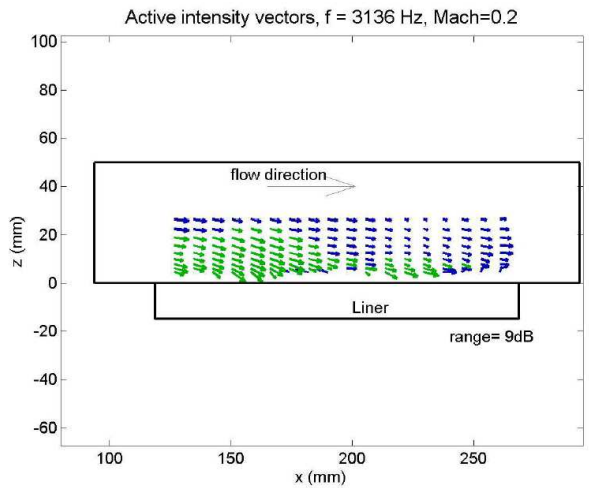
LDV measurement ⇒ υ', V_{ref} ⇒ ξ_x, ξ_z ⇒ Other acoustic parameters

Z, I, ...



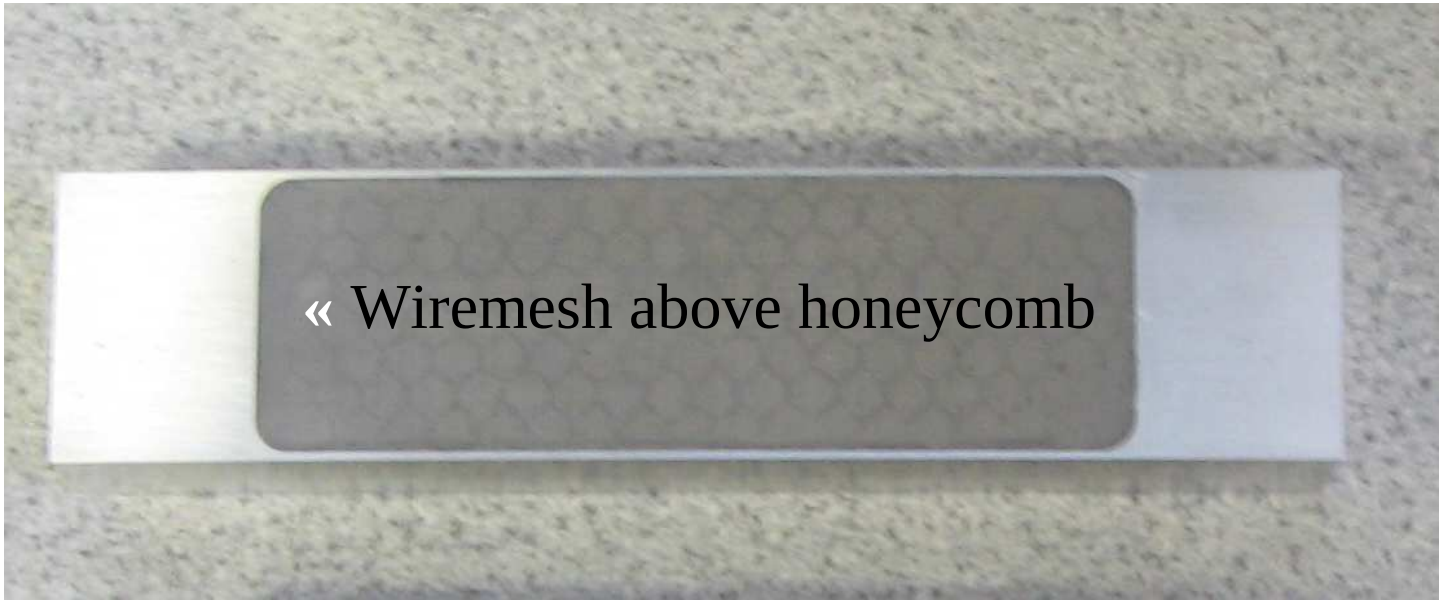
$$V = V_{ref} + \upsilon' + \cancel{V_{turb}}$$





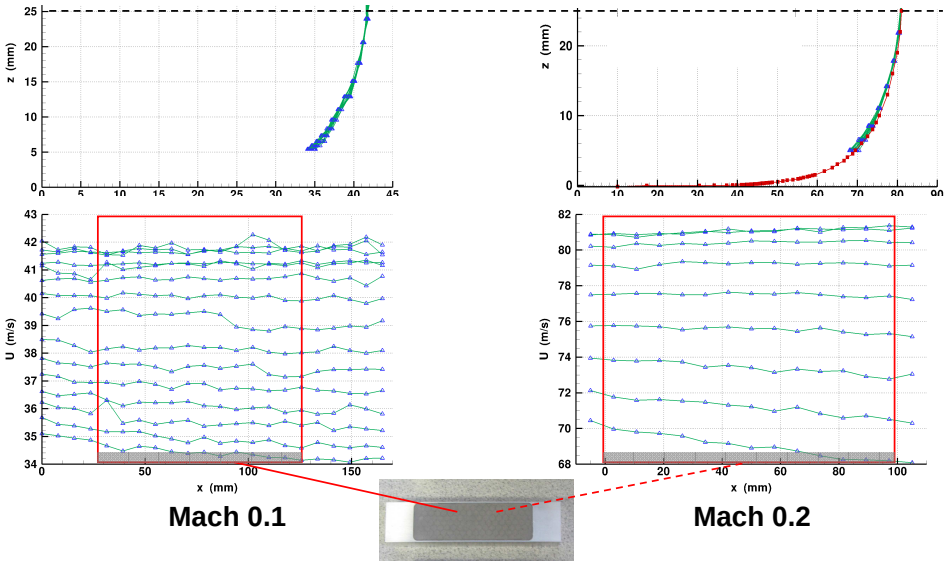
MINOTTI A., SIMON F. and GANTIÉ F., Aerospace Science and Technology (2007)

Ex. of “In-situ” measurement with grazing flow



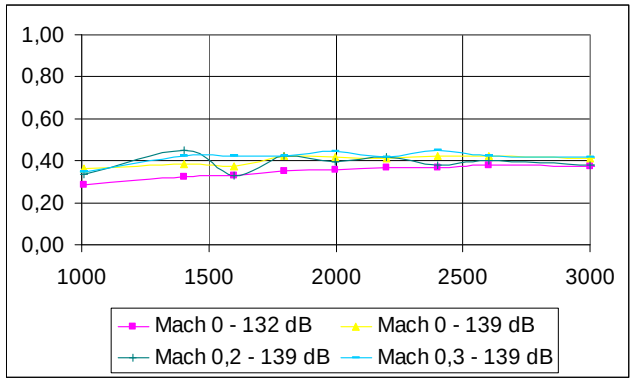
Ex. of “In-situ” measurement with grazing flow

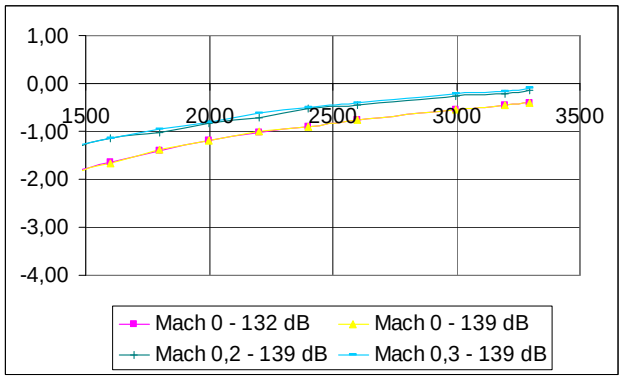
Aerodynamic boundary layer by LDV 2C



Mach 0.1 Mach 0.2

$$\frac{R}{\rho c}$$



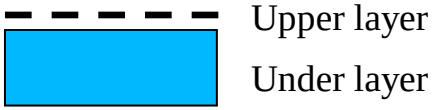


$$\frac{X}{\rho c}$$

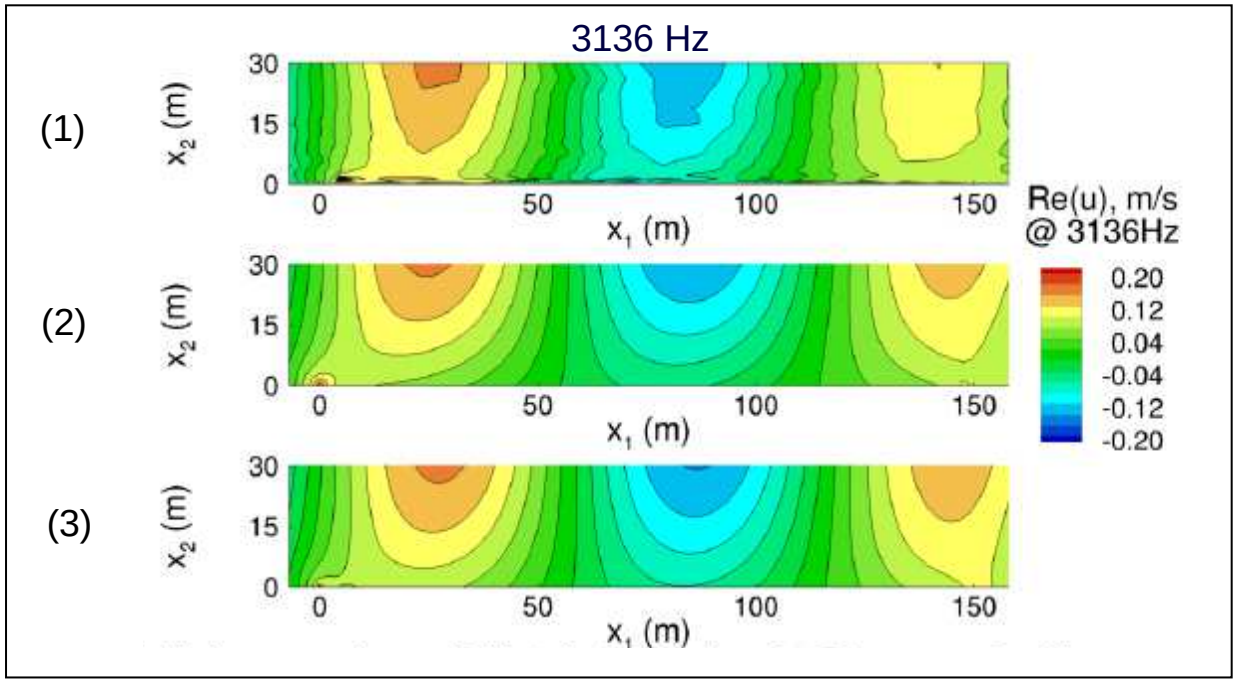
Impedance « In-situ »

Comparison between direct computations / LDV measurements above a liner

« Micro-holes » layer above honeycomb



- Porosity: 5 %
- Layer thickness : 0.8 mm
- Hole diameter: 0.3 mm
- Honeycomb thickness : 20 mm

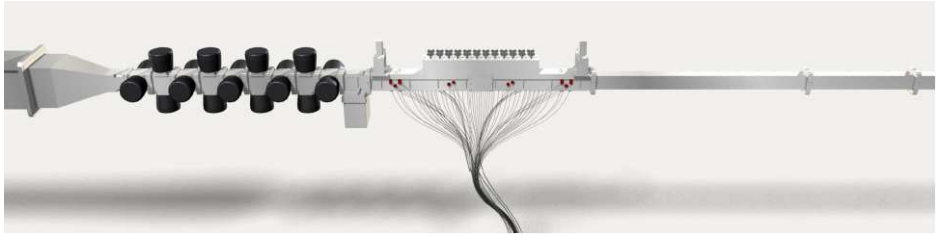


(1) LDV : Acoustic velocity field
(2) Computation with Discountinuous Galerkin Scheme) + Z by « Combined LDV-microphone »
(3) Computation with Discountinuous Galerkin Scheme) + Z by Melling theory

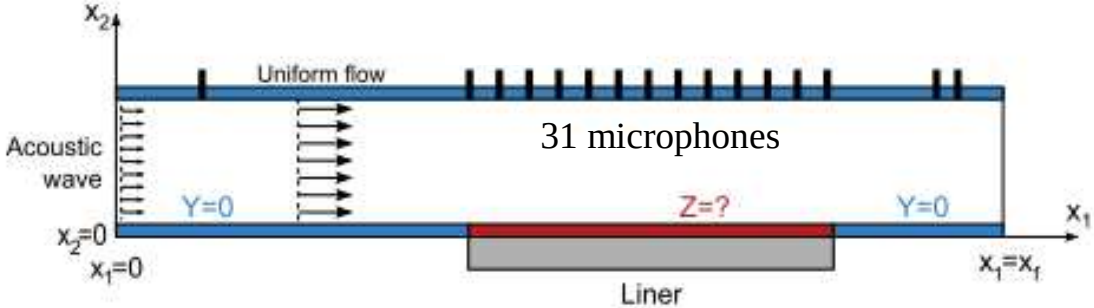
Acoustic impedance eduction

Inverse methods mainly characterized by:

- The propagation model (and the associated numerical scheme): **convected Helmholtz, FEM**
- The measured quantity and its localization: **acoustic pressure at the wall opposite the test liner**
- The objective function to be minimized: **acoustic pressure**



NASA duct configuration

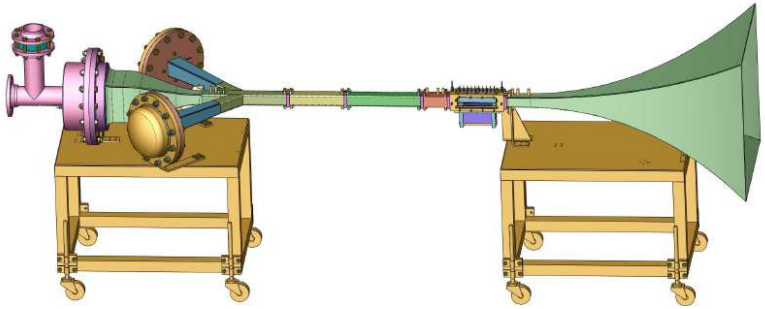


$$\mathcal{J}(\boldsymbol{\varphi}, z, C) = \sum_{m=1}^{N} \| p_{\text{calc}}^{m} - p_{\text{meas}}^{m} \|^2$$

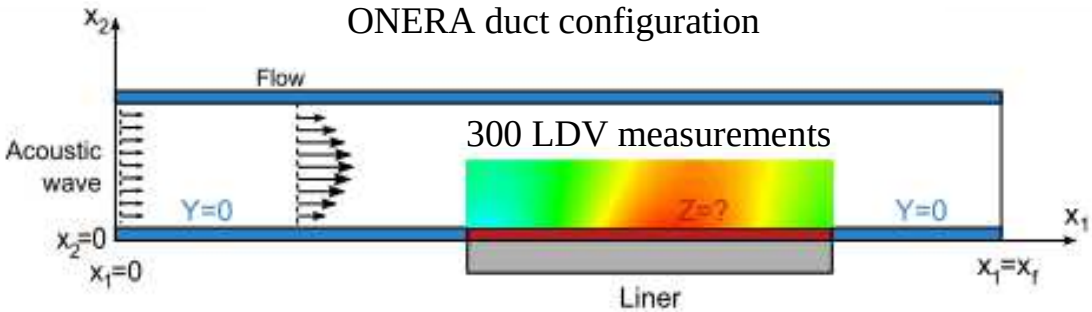
Acoustic impedance eduction

Inverse methods mainly characterized by:

- The propagation model (and the associated numerical scheme): **Linearized Euler Equations (LEE), Discontinuous Galerkin (DG)**
- The measured quantity and its localization: **acoustic velocity above the liner (LDV)**
- The objective function to be minimized: **acoustic velocity**



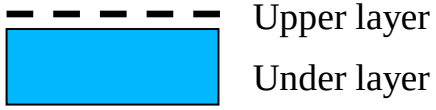
ONERA duct configuration



$$\mathscr{J}_{red} = \frac{\int_\Omega \|\mathbf{u}_{meas} - \mathbf{u}_{calc}\|^2 \, \mathrm{I}_{\Omega_{obs}}(\mathbf{x})}{\int_\Omega \|\mathbf{u}_{meas}\|^2 \, \mathrm{I}_{\Omega_{obs}}(\mathbf{x})}$$

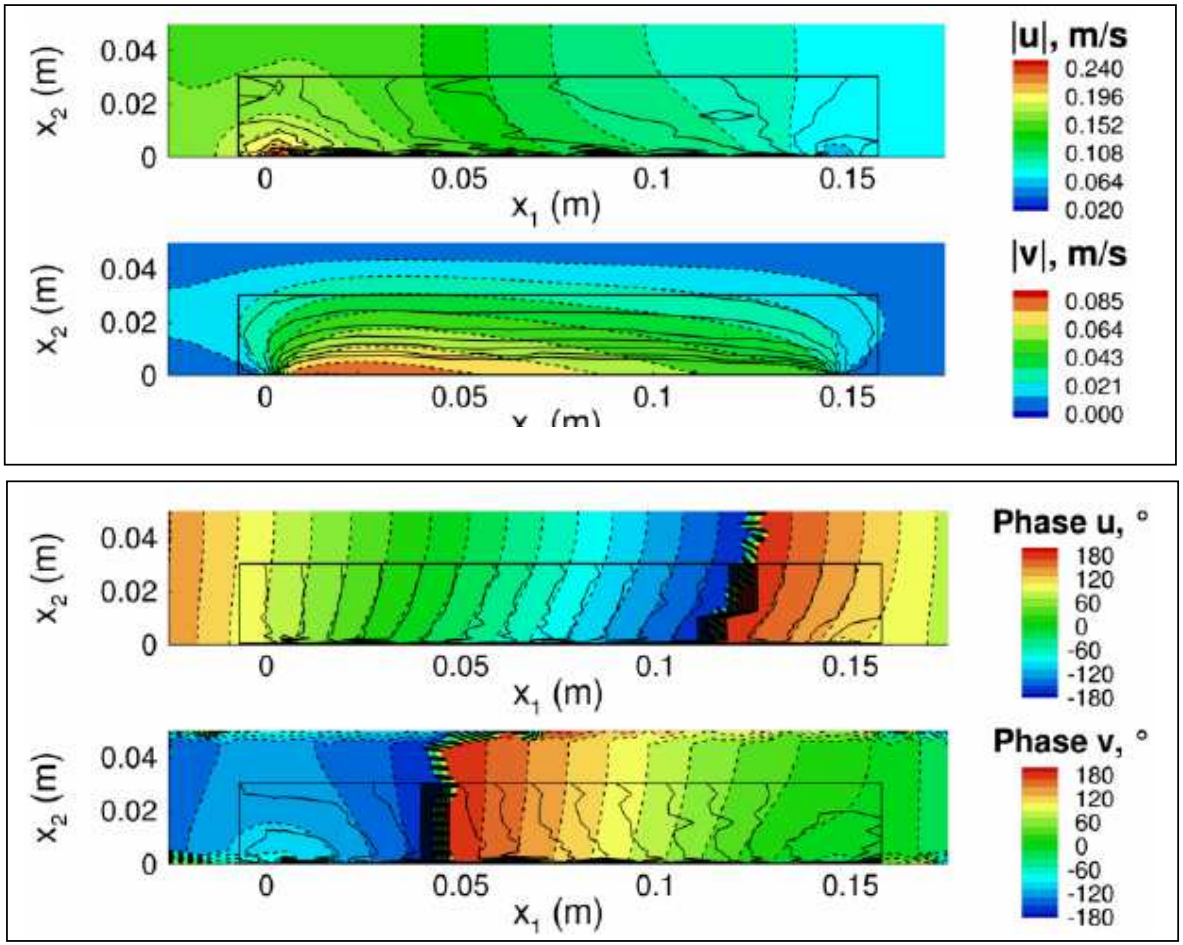
Comparison between direct computations with educed impedance / LDV measurements above a linear liner

« Micro-holes » layer above honeycomb



- Porosity: 5 %
- Layer thickness : 0.8 mm
- Hole diameter: 0.3 mm
- Honeycomb thickness : 20 mm

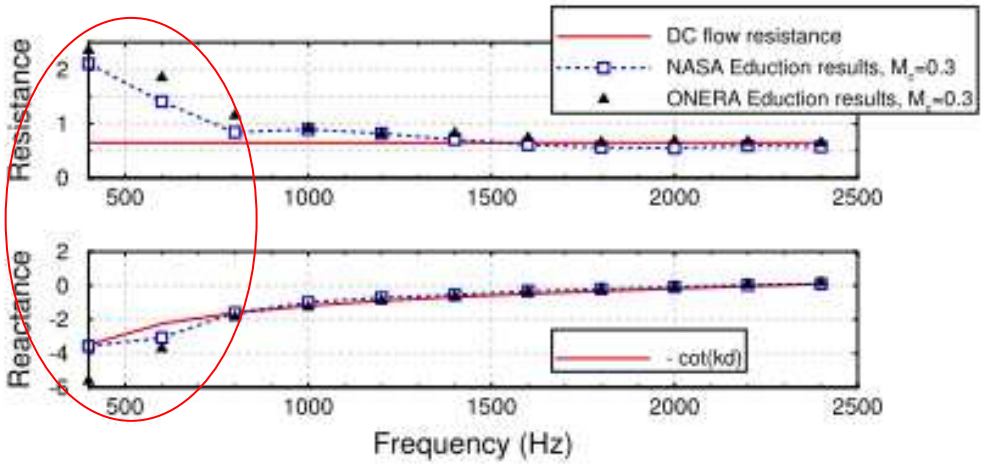
1992 Hz



PIOT E., PRIMUS J., SIMON F., 33rd AIAA Aeroacoustics Conference, june 2012.

Comparison of NASA / Onera techniques

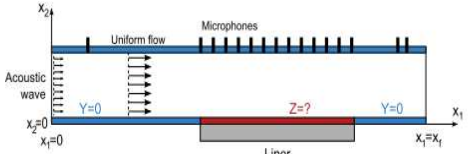
- NASA set of acoustic pressure measurements on a « linear » liner (wiremesh), with and without flow
- Run of NASA impedance eduction code (Jones & Watson, AIAA-2011-2865)
- Run of Onera impedance eduction code with pressure-based objective function



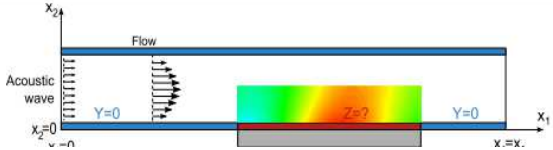
Perfect agreement between both codes, except at low frequency for the $M_c = 0.3$ case (influence of mean flow profile?)

PRIMUS J., PIOT E., SIMON F., Journal of Sound and Vibration 332 (2013) 58–75

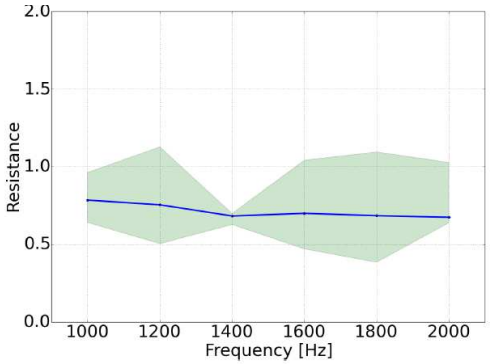
Acoustic impedance eduction above a liner with Onera process



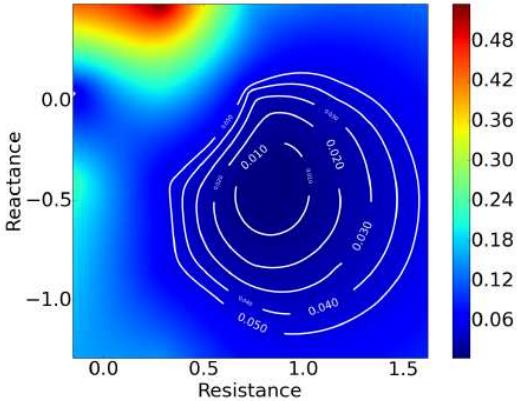
NASA data base



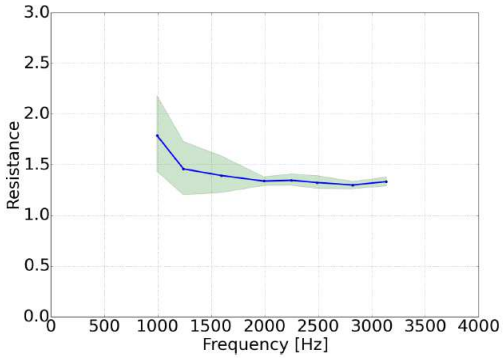
Onera data base



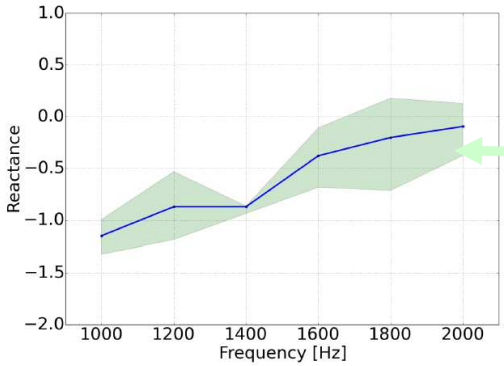
(a) Resistance



Map in the impedance plane

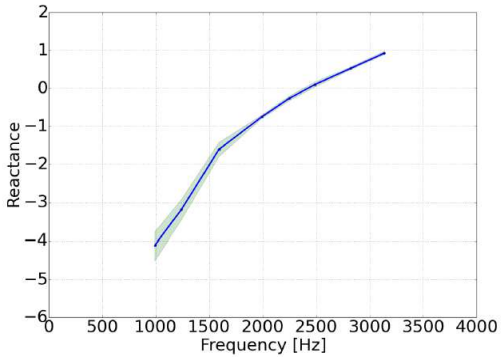


(a) Resistance



(b) Reactance

Confidence interval for dimensionless objective function < 1 %



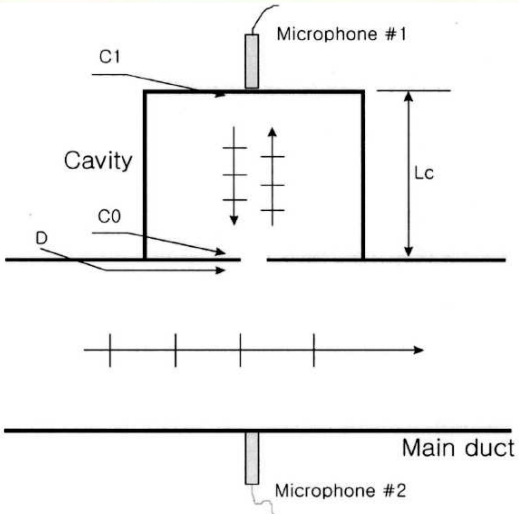
(b) Reactance

Wiremesh + honeycomb, M=0.3

« Micro-holes » layer + honeycomb, M=0.23

BERENGUÉ LLONCH O., PIOT E., SIMON F., CFA 2014

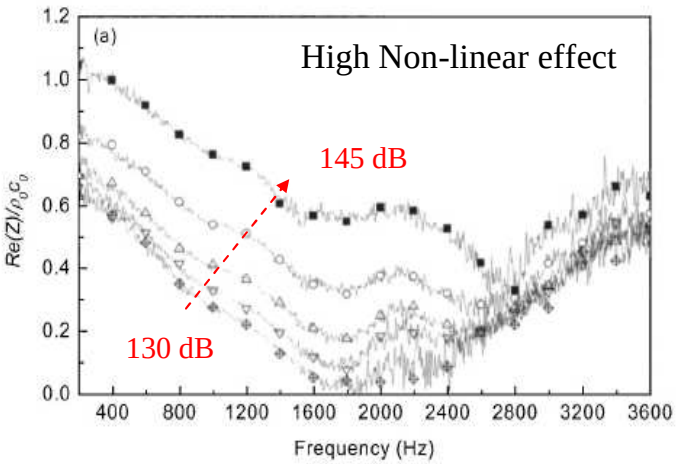
Influence of overall sound pressure

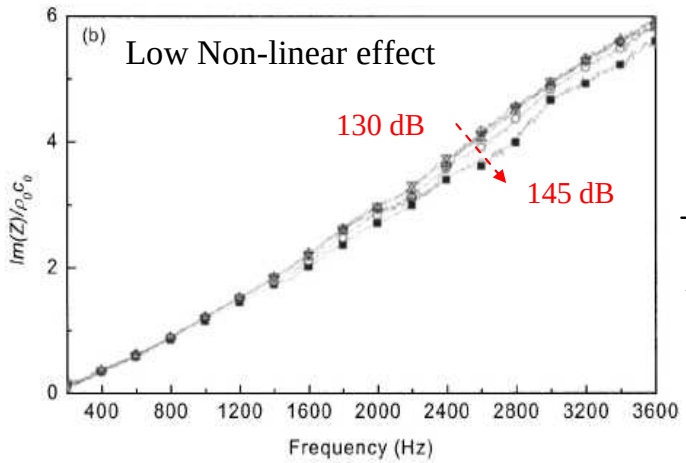


$$Z_n = Z/\rho_0 c_0 = \frac{[H_{12} - \cos kL_C]}{j \sin kL_C}$$

Measured orifice impedance
(M=0.1, d = 4 mm, l = 1 mm, σ=5.59 %)

$\frac{R}{\rho c}$



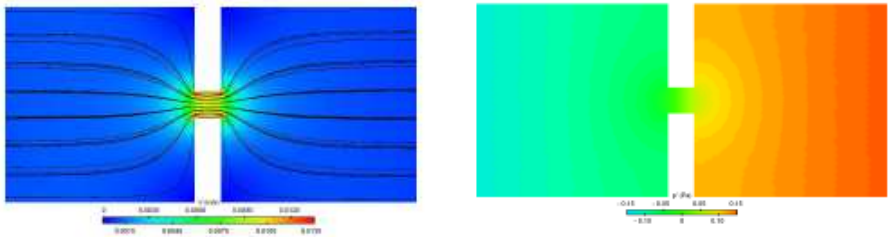


$\frac{X}{\rho c}$

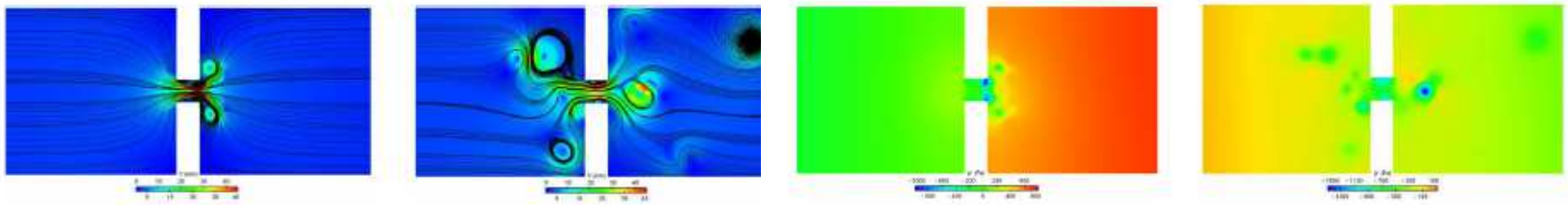
LEE S.H. and IH J.G., "Empirical model of the acoustic impedance of a circular orifice in grazing mean flow", *J. Acoust. Soc. Am.*, 114 (2003)

Influence of overall sound pressure

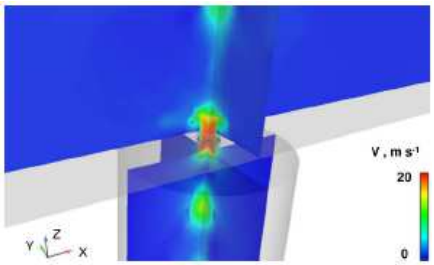
Simulation 2D/3D



Instantaneous velocity and pressure fields, 2D DNS, 3.5 KHz, 80 dB

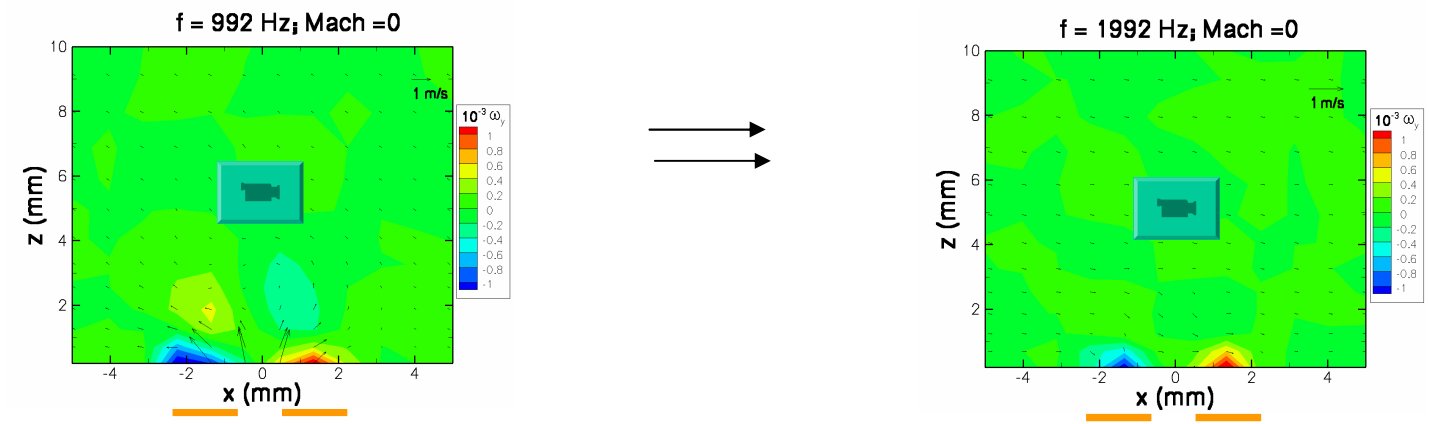


Instantaneous velocity and pressure fields, 2D DNS, 3.5 KHz, 150 dB

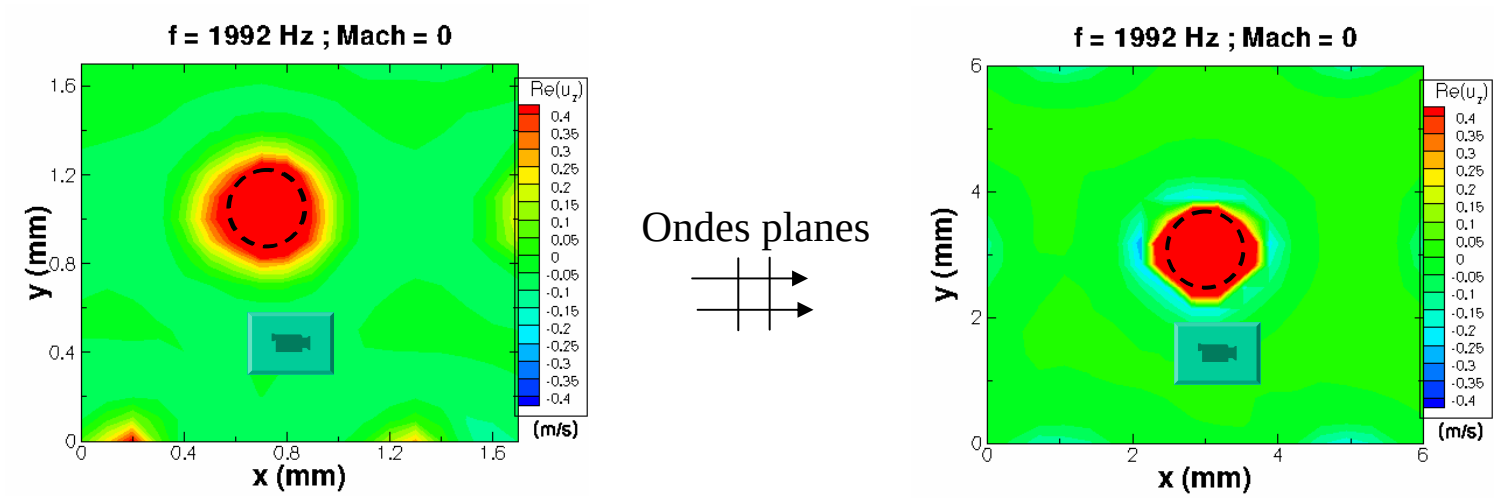


ROCHE J., LEYLEKIAN L. and VUILLOT F. , "2D-axisymmetric and 3D computational study of the acoustic absorption of resonant liners", Internoise 2008.

Influence of overall sound pressure

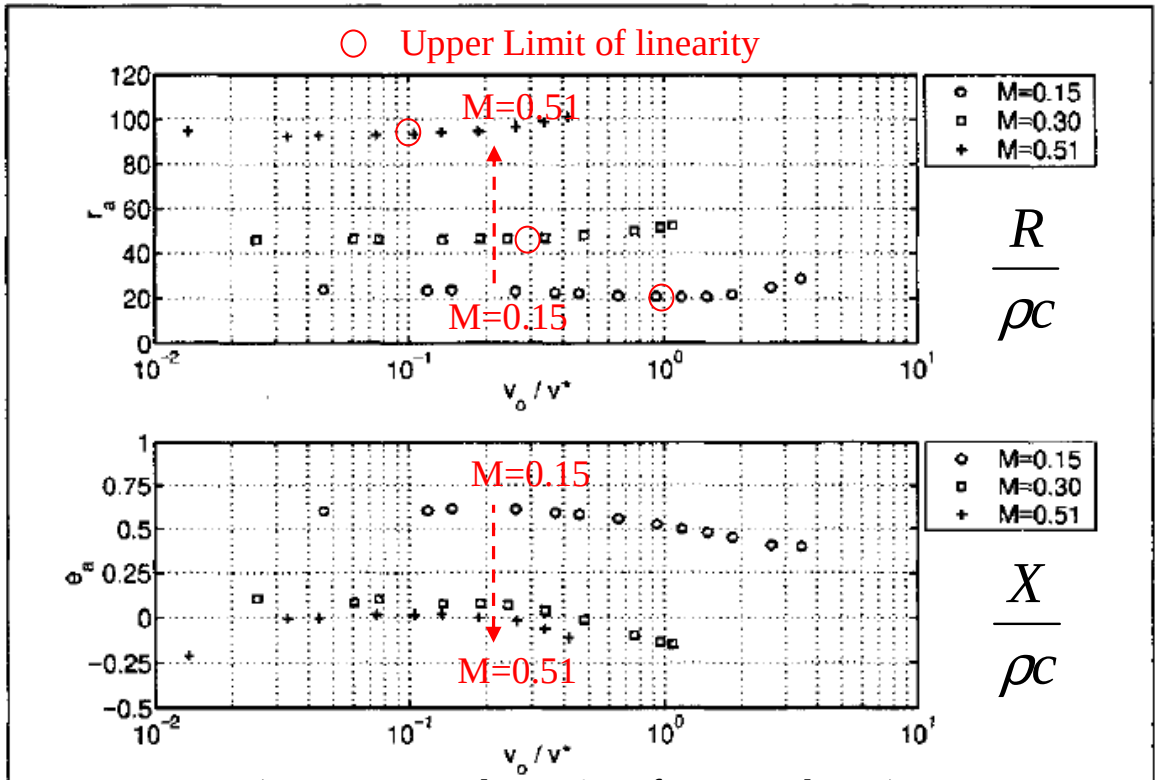


Vorticity field (Onera) around a resonator hole (Diameter : 1 mm), LDV, M 0, 1 or 2 kHz



Normal acoustic velocity field (Onera) around a resonator hole (Diameter: 0.3 or 1 mm), LDV, M 0, 2 kHz, 100 dB

Influence of grazing flow



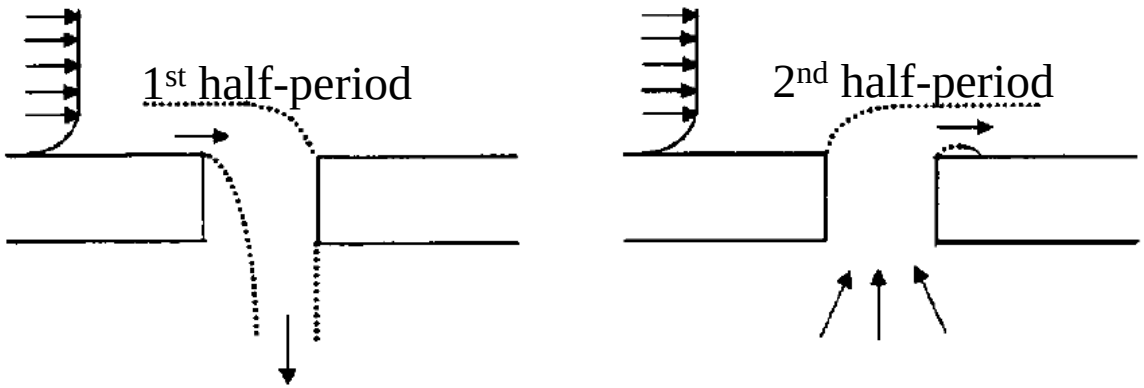
(V_0 acoustic velocity / V* friction velocity)

« Resistive layer » impedance measured with « in-situ » method
(d = 0.68 mm, *l* = 1.02 mm, σ=1.39 %, 3150 Hz)

MALMARY C., CARBONNE S., AUREGAN Y. and PAGNEUX V., "Acoustic Impedance Measurement with Grazing Flow", 7th AIAA/CEAS Aeroacoustics Conference, (2001)

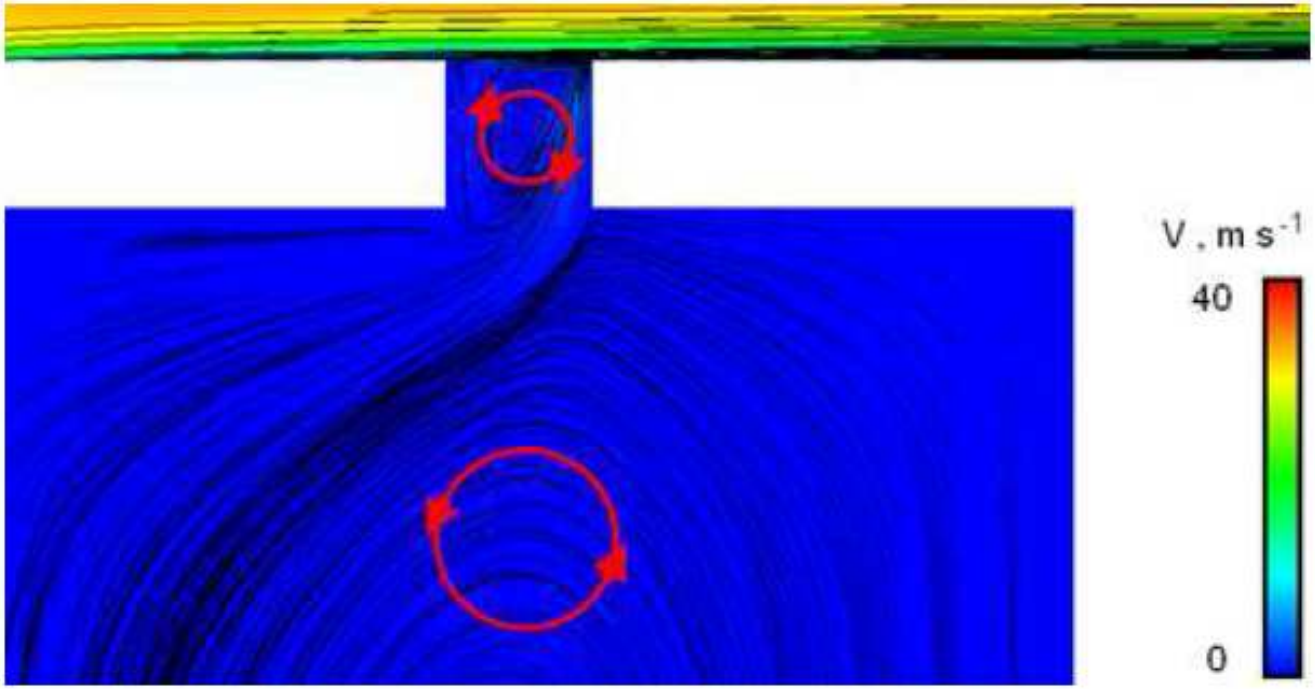
Influence of grazing flow

A physical explanation of grazing flow is given by Hersh :
"The interaction between the grazing flow and sound-pressure field causes some of the grazing flow to be injected into the cavity over the inflow half-cycle and then ejected over the outflow half-cycle.
In both cases, the effective area through which the sound particle volume flow enters and exit the cavity appears to be less than the orifice area".



HERSH A.S. and WALKER B.E., “Acoustic behavior of Helmholtz resonators: part II. Effects of grazing flow", *CEAS/AIAA, CEAS/AIAA-95-079 (1995)*

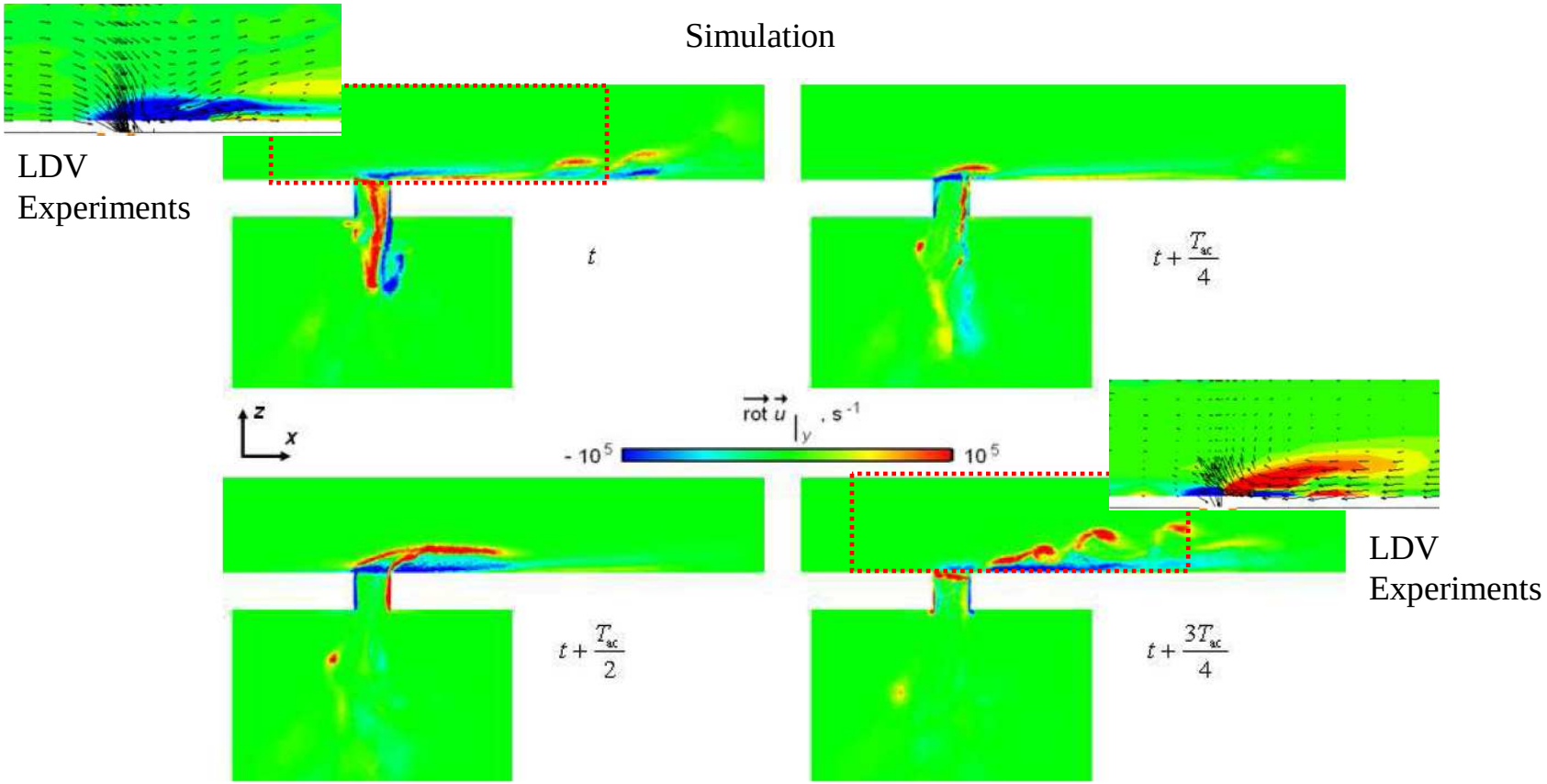
Influence of grazing flow



Aerodynamic velocity field and streamline pattern around a resonator hole, 3D DNS, M 0.1

ROCHE J., VUILLOT F., LEYLEKIAN L. , DELATTRE G., PIOT E., SIMON F., " Numerical and Experimental Study of Resonant Liners Aeroacoustic Absorption Under Grazing Flow", 16th AIAA/CEAS Aeroacoustics Conference, 2010.

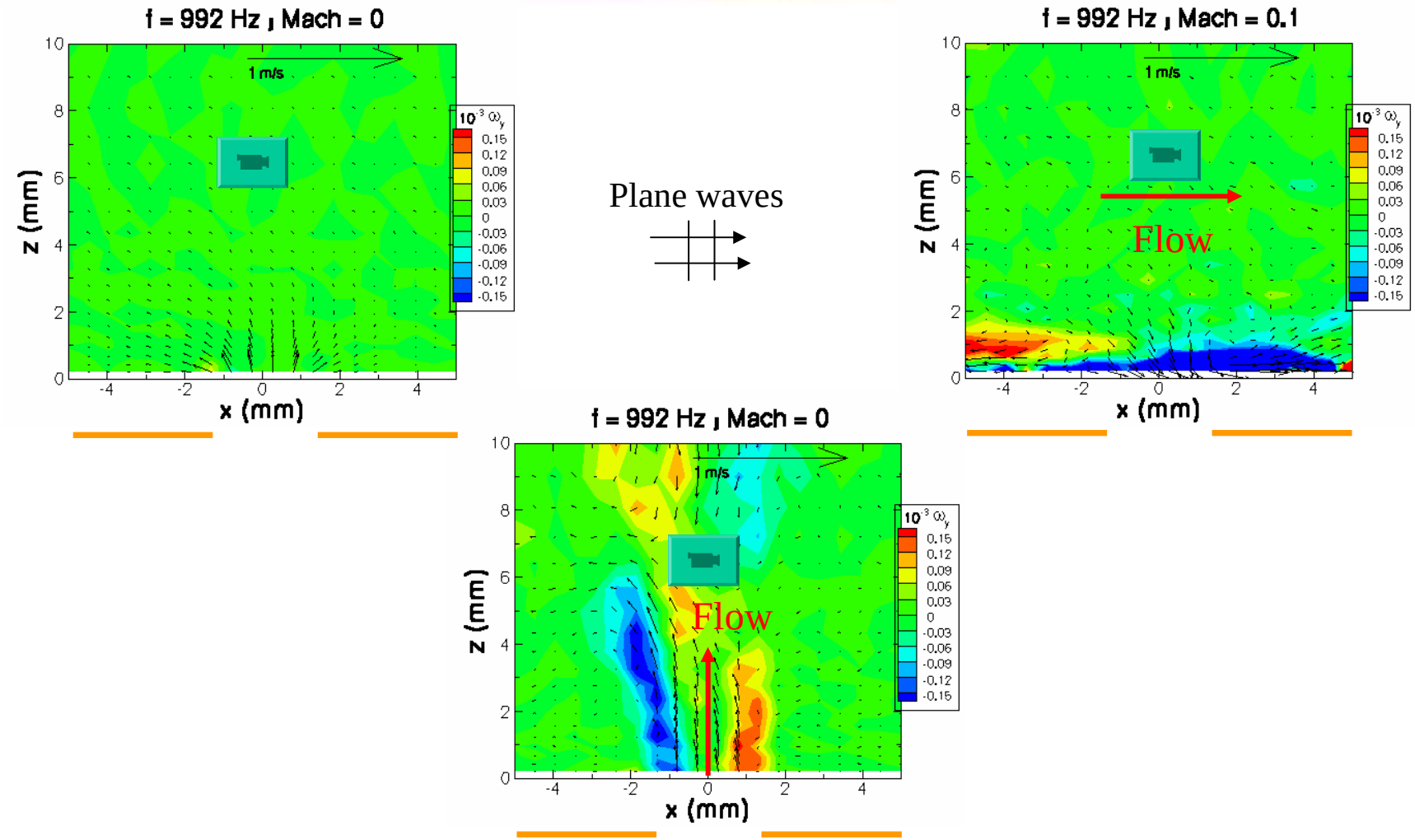
Influence of grazing flow



Vorticity field around a resonator hole, **3D DNS**, M 0.1, 1.5 kHz, 140 dB

ROCHE J., VUILLOT F., LEYLEKIAN L. , DELATTRE G., PIOT E., SIMON F., " Numerical and Experimental Study of Resonant Liners Aeroacoustic Absorption Under Grazing Flow", 16th AIAA/CEAS Aeroacoustics Conference, 2010.

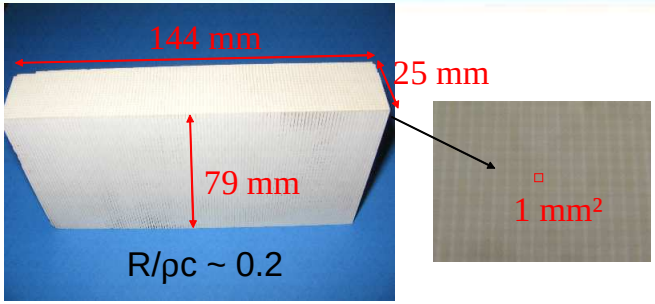
Influence of grazing or transverse flow



Vorticity field (Onera) around a resonator hole, LDV, M 0.1, 1 kHz, 100-110 dB

« Hydrodynamic" modes with grazing flow

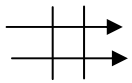
Sample **COMATEC**



1000 Hz, M=0.3

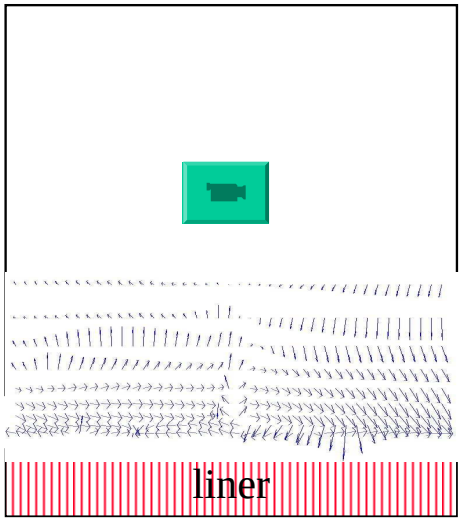
Longitudinal turbulence rate

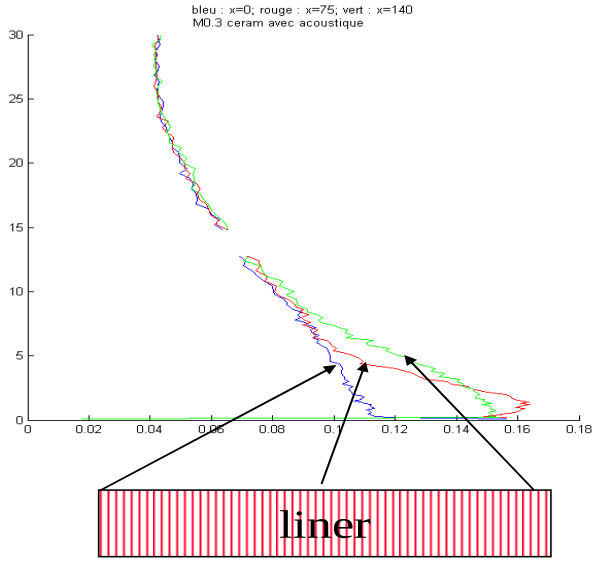
Plane waves



V

8 mm





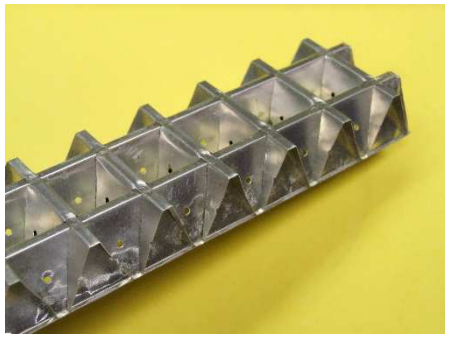
Non-linear behaviour due to "hydrodynamic" modes increased by the acoustic resonance of the porous material and shear flow

PETHIEU R., SIMON. F., MICHELI F. MOTAR 2008

Other concepts of locally reacting liners studied at Onera

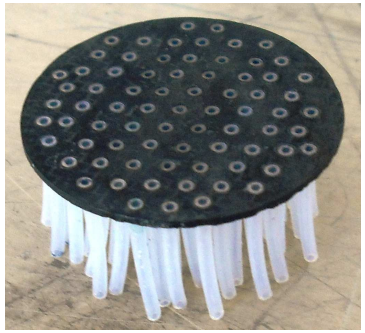
"Honeycomb" ULSAP

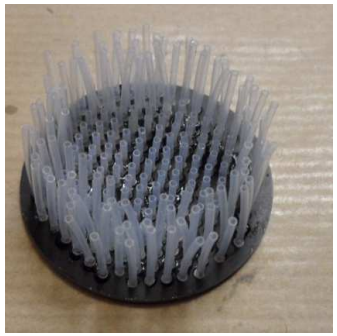
(Leylekian, 2009)



Perforated plate with flexible hollow tubes

(Simon 2013)

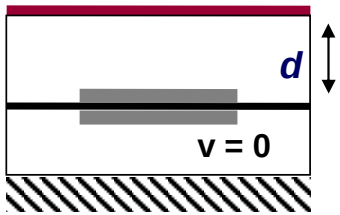




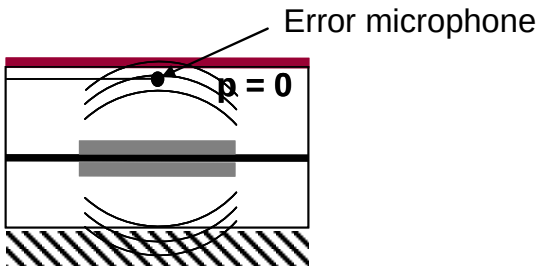
- "Active-passive" liner

(Betgen et al., 2012)

Passive mode



Active mode

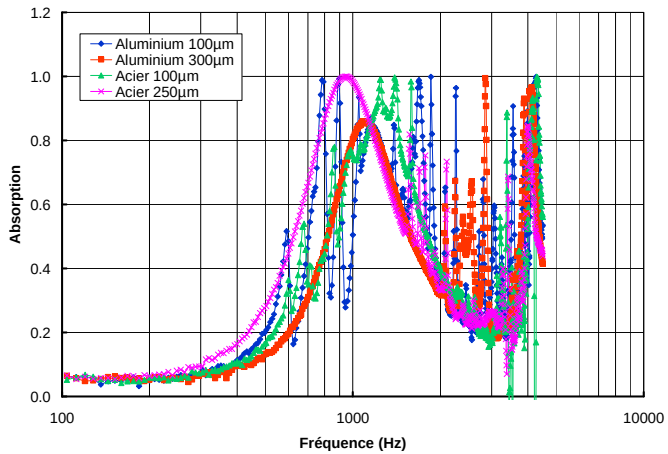


Honeycomb « ULSAP »

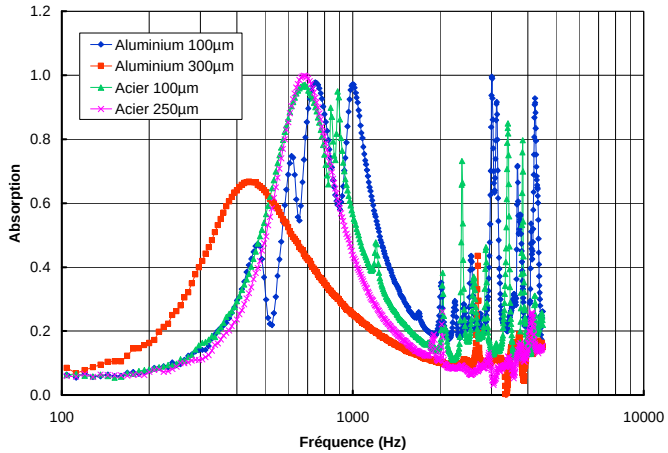
- Non-linearity by vibration

Aluminium layer : 1 and 3/10 mm
Steel layer : 1 and 2.5/10 mm

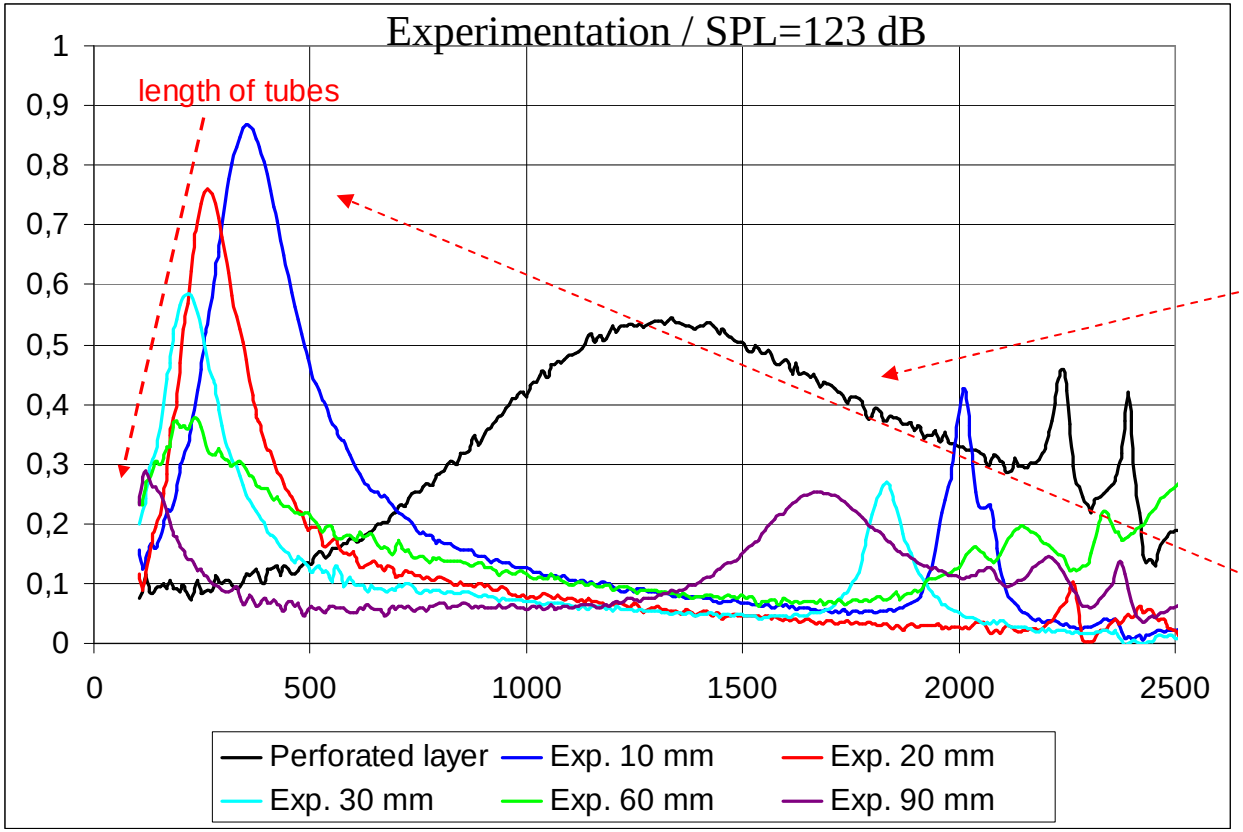
Without glue

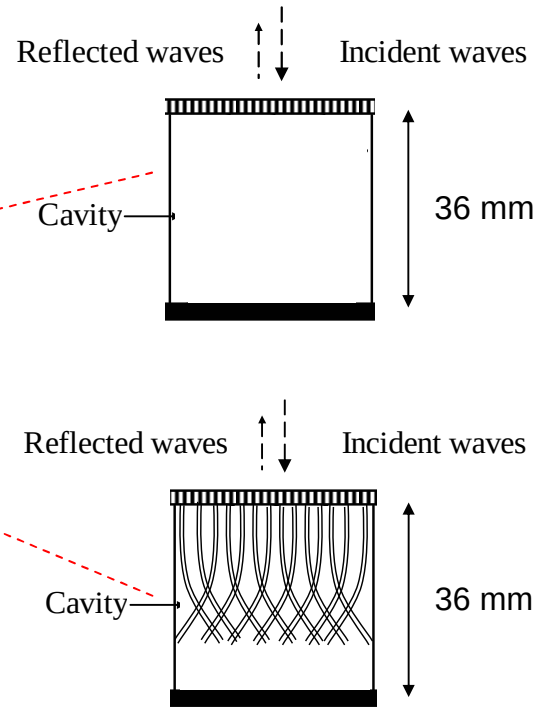


With glue



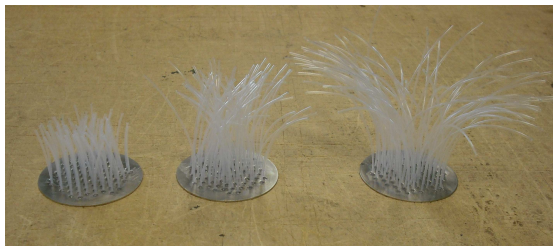
Perforated plate with flexible hollow tubes





With actual turbofan, frequencies above 2000 Hz

With UHBR engines, shorter and thinner nacelles so frequencies under 500 Hz

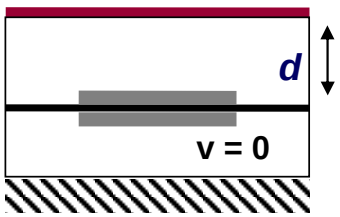


SIMON F., ICA 2013

« Active-passive » liner

Passive mode

- Behaves as a classical passive absorber, mainly depending on ***d***



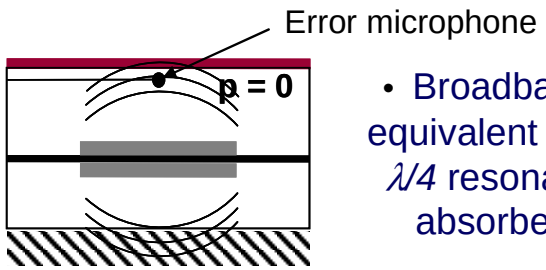
Resistive layer

R = σ e

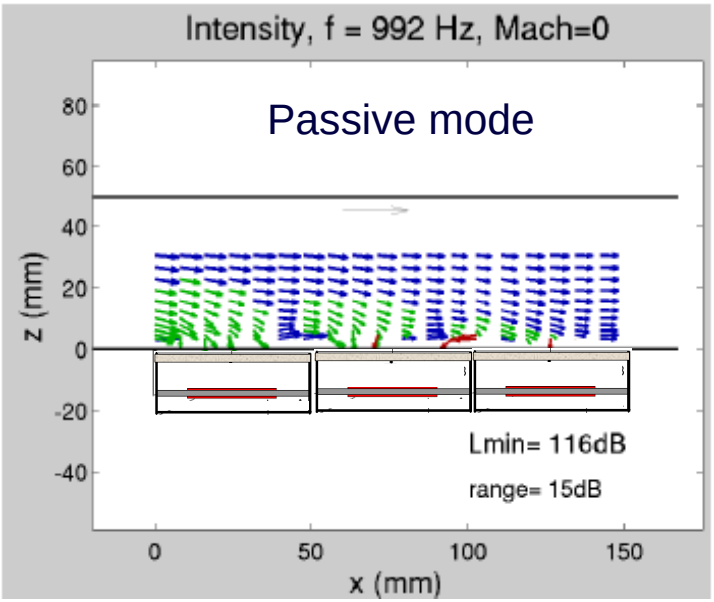
Actuator

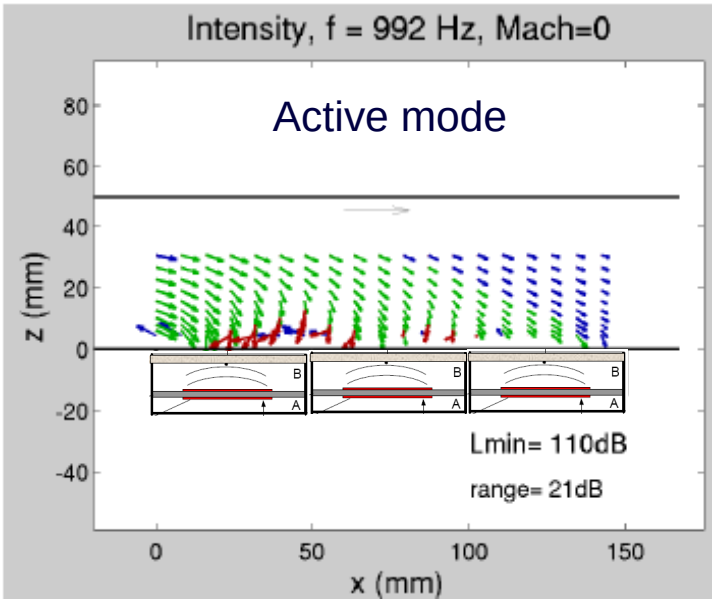
Rigid wall

Active mode



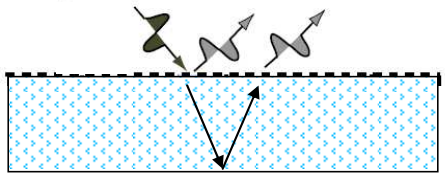
- Broadband equivalent of a *λ/4* resonant absorber





BETGEN B., GALLAND M-A, PIOT E., SIMON F. -Applied Acoustics 73 (2012)

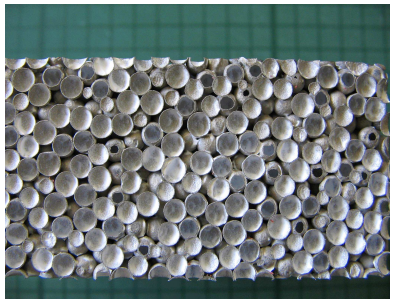
Non-locally reacting liners



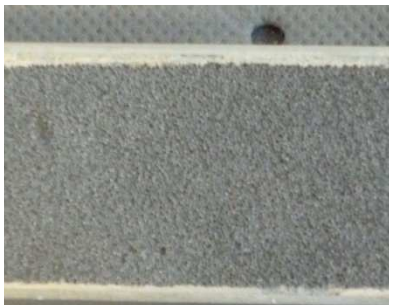
~~Acoustic impedance~~

Fiber medium

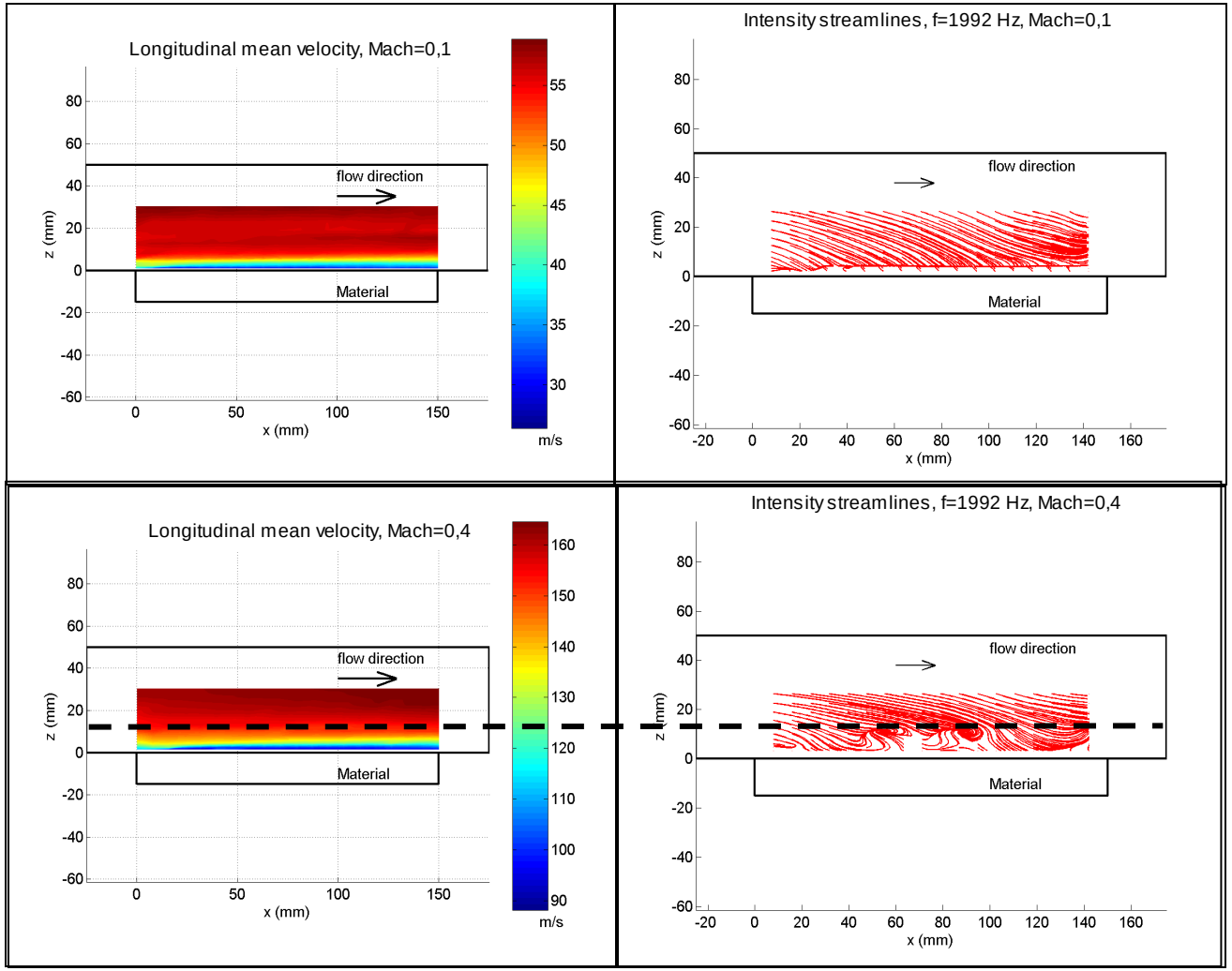
Hollow spheres



Foam



Effect of « non-locally behaviour » above fiber medium



Mach 0.1

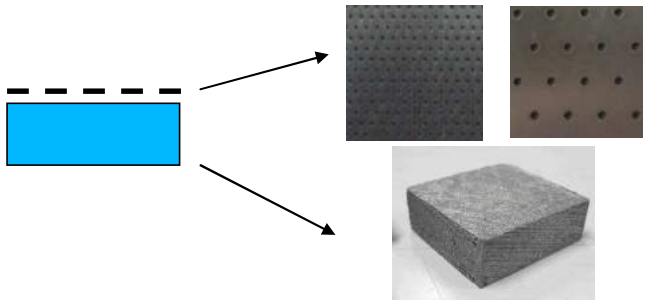
Metallic fibers
Intensity field 2D
2000 Hz

Mach 0.4

B2A experiments

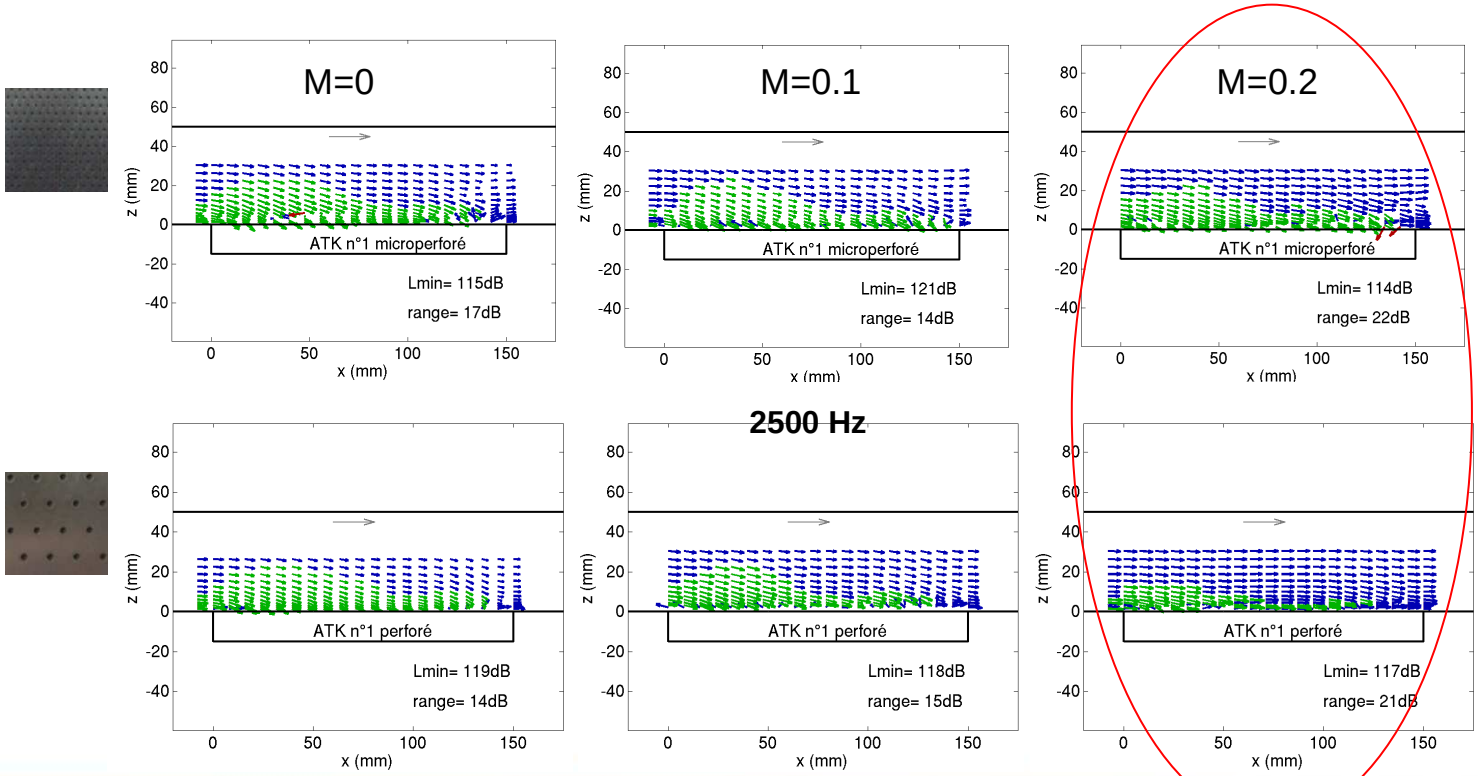
Effect of « non-locally behaviour » above (micro-)perforated resistive layer with fiber medium

resistive plate



Porosity: 5 %
Layer thickness: 0.8 mm
Hole diameter: 0.3 or 1 mm

Layer thickness: 20 mm



Acoustic porous solutions for interior noise

ONERA

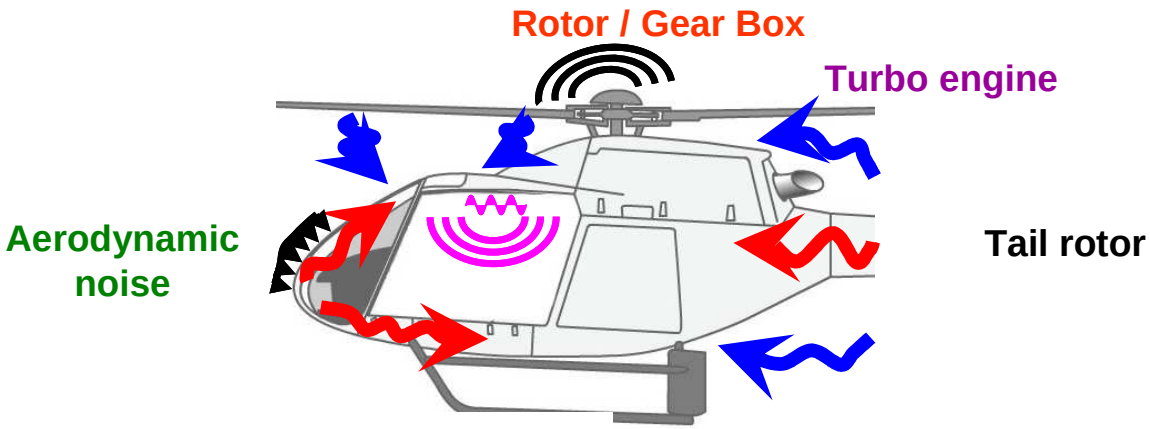
THE FRENCH AEROSPACE LAB

return on innovation

Context

Porous materials to reduce noise radiated in helicopter cabin

- Noise level in helicopter cabin noticeably higher than the noise inside commercial and executive jets
  - Generated by main and tail rotors, Turbo engine, main gearbox and turbulent boundary layer.



SIMON *et al.*, Activities of European Research Laboratories Regarding Helicopter Internal Noise, Journal AerospaceLab, Paper n° AL07-04 DOI : 10.12762/2014.AL07-04

Context

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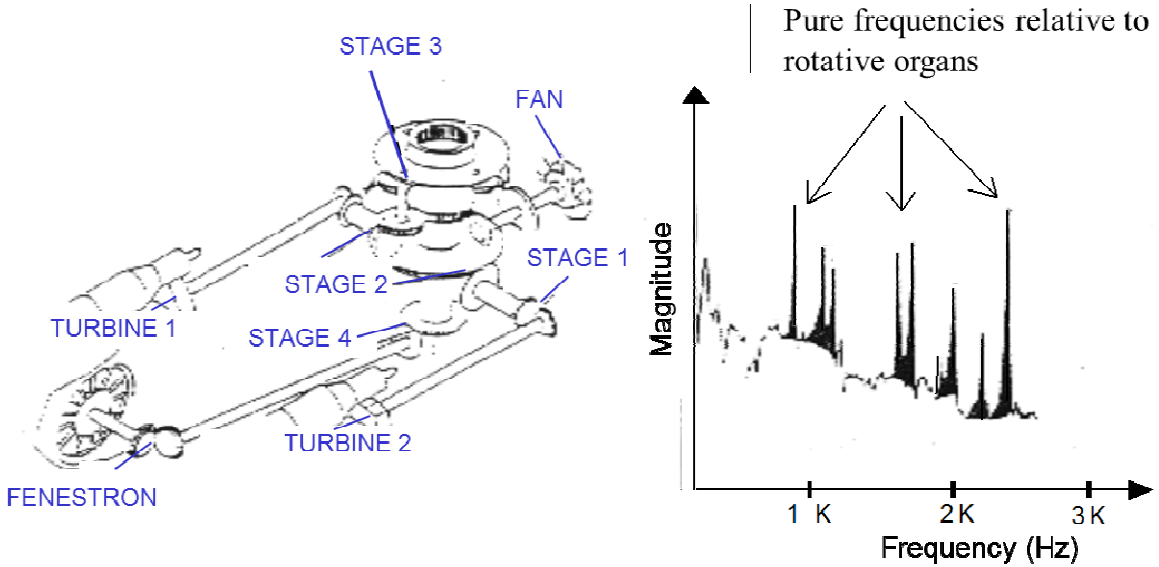
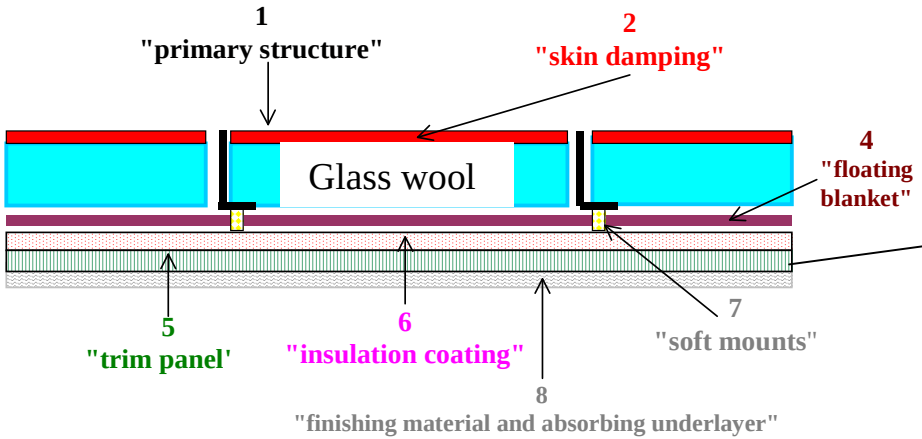


DUSSAC *et al.*, "A finite element method to predict internal noise levels at discrete frequencies for a partially composite helicopter fuselage", AHS annual forum, 1989.

Helicopter “global wall”

i.e. AGUSTA AW139 EXECUTIVE
(Custom Pininfarina Edition)

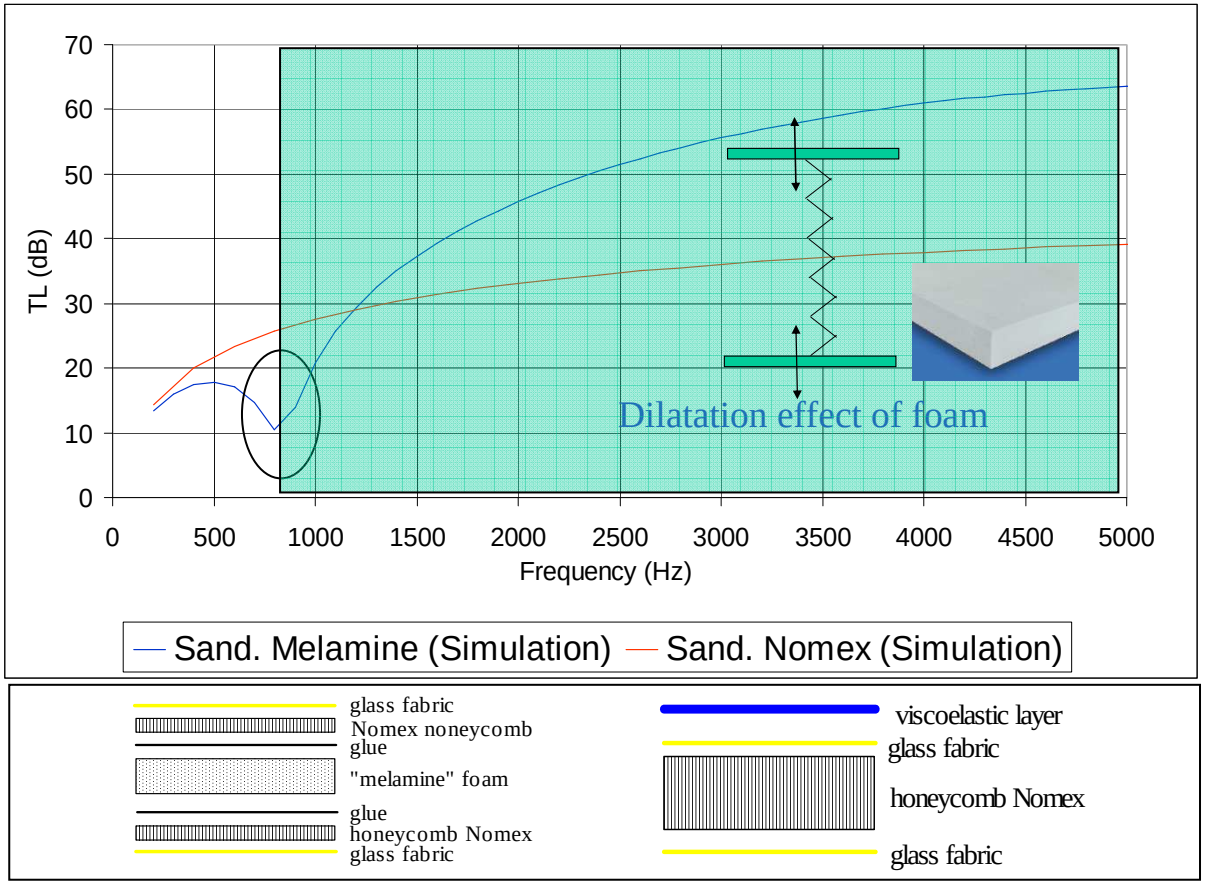
i.e. Eurocopter EC 135
(Configuration "business" Hermes)

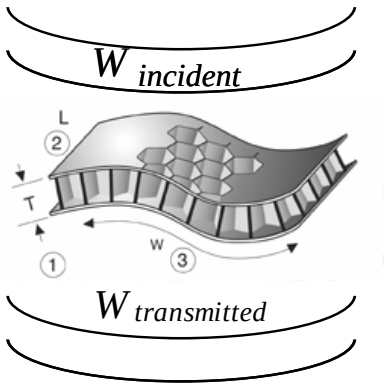


Honeycomb sandwich panel
with front side **open or closed**
with suede on soft foam layer

For absorption or transmission loss

Transmission Loss (TL) of «honeycomb» sandwich panel and of « other concept » with porous material

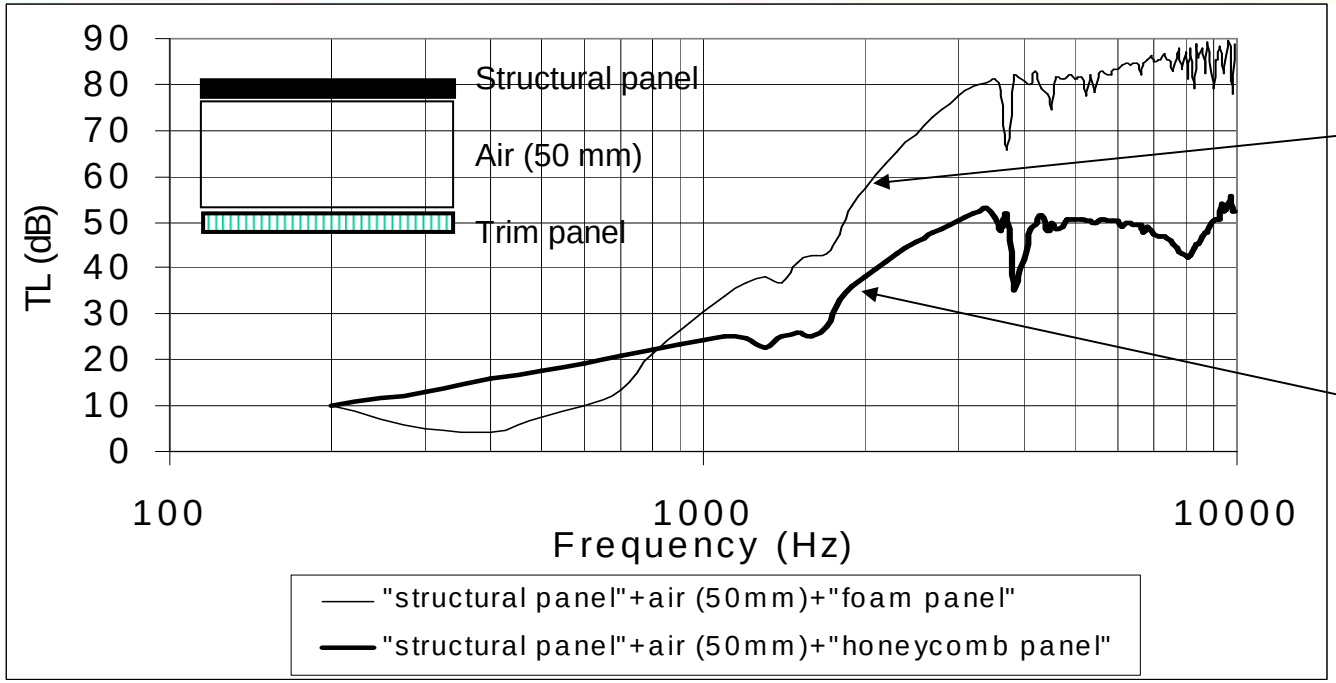




$$TL = 10\log\left(\frac{W_{incident}}{W_{transmitted}}\right)$$

- High acoustic Transmission Loss due to dilatation effect of foam (elastic waves)
- Satisfying static bending stiffness due to honeycombs

Transmission Loss of «global wall » with honeycomb» and «foam» sandwich panels



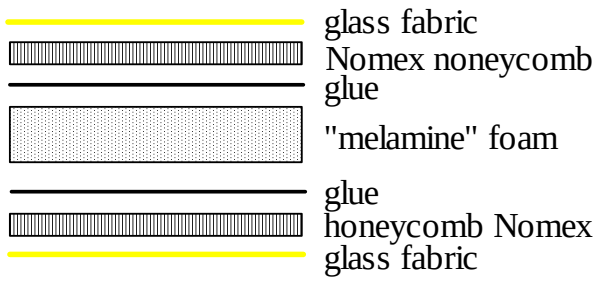
After dilatation of foam (elastic waves) and of cavity (acoustic waves)

After dilatation of cavity (acoustic waves)

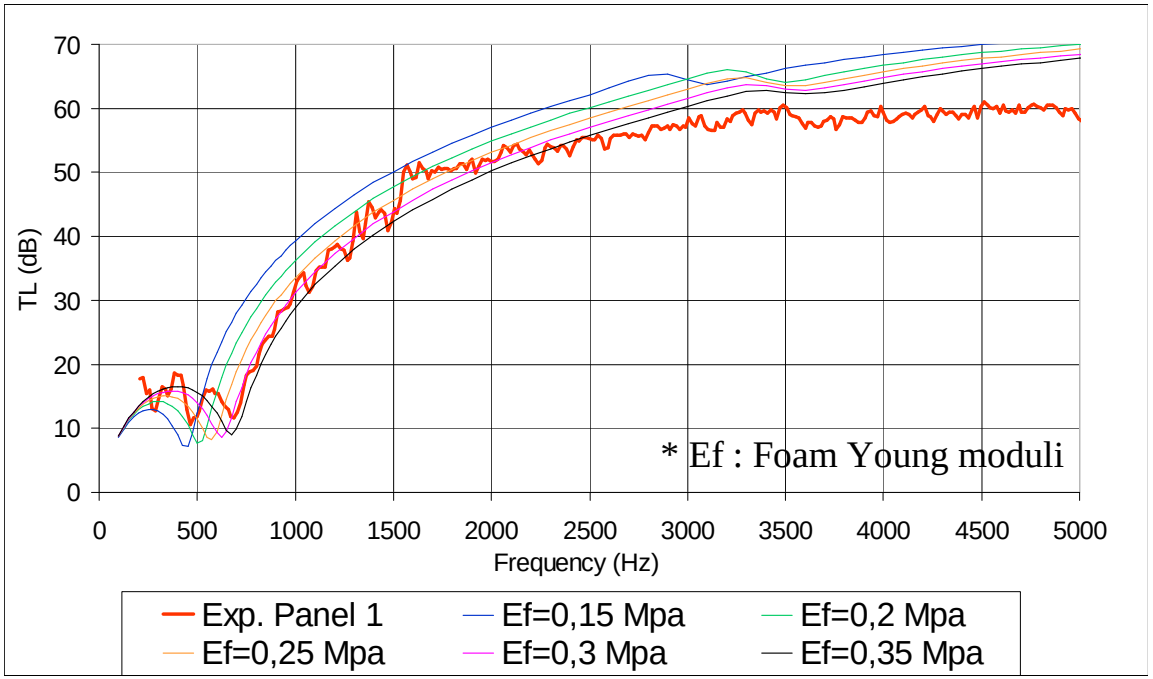
Panel	Structural panel	"Honeycomb and viscoelastic layer" trim panel	"Foam" trim panel
Surfacic mass (kg/m2)	16.5	8.3	5.4
Thickness (mm)	2.8	11	18.1

SIMON F., PAUZIN S., BIRON D., ERF30, 2004.

Optimised passive trim panel:
Symmetric sandwich panel with honeycombs and foam



Thickness: ~ 20 mm
Surfacic mass: ~ 6 kg/m²
(V.I.P. requirements)

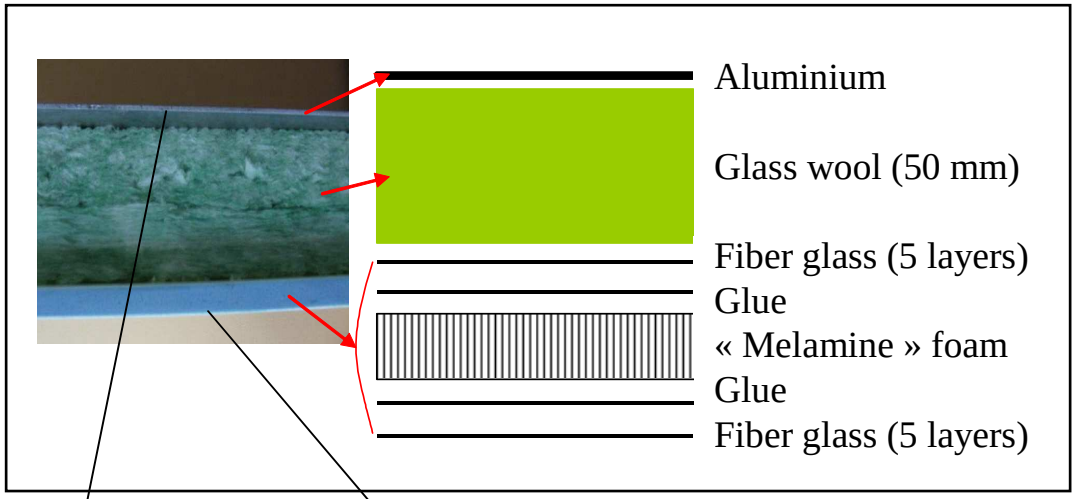


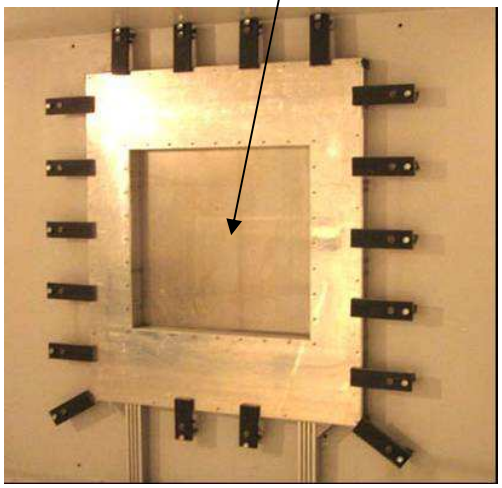
Manufacturing process:

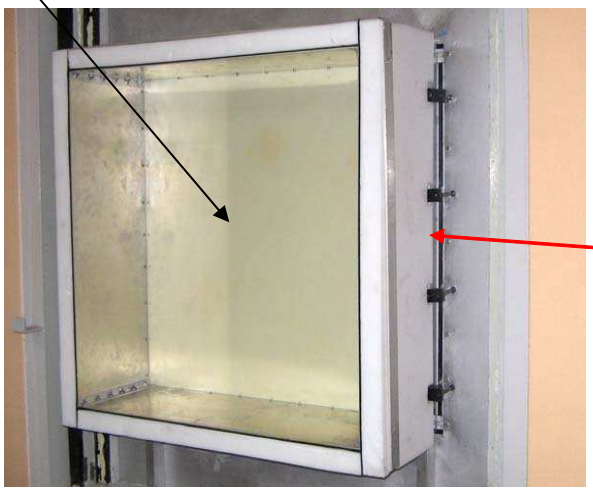
- Polymerization of "glass fabric / honeycomb" layers under vacuum at 120°C
  - Control of total thickness of "glass fabric / honeycomb"
- Application of glue on foam sides with spatula
- "glass fabric / honeycomb" layers + "glue / foam" under vacuum
- Polymerization under mass at 60° C
  - Control of total thickness of "glass fabric / honeycomb"
- Complete relaxation of foam

UE project
« Friendcopter »

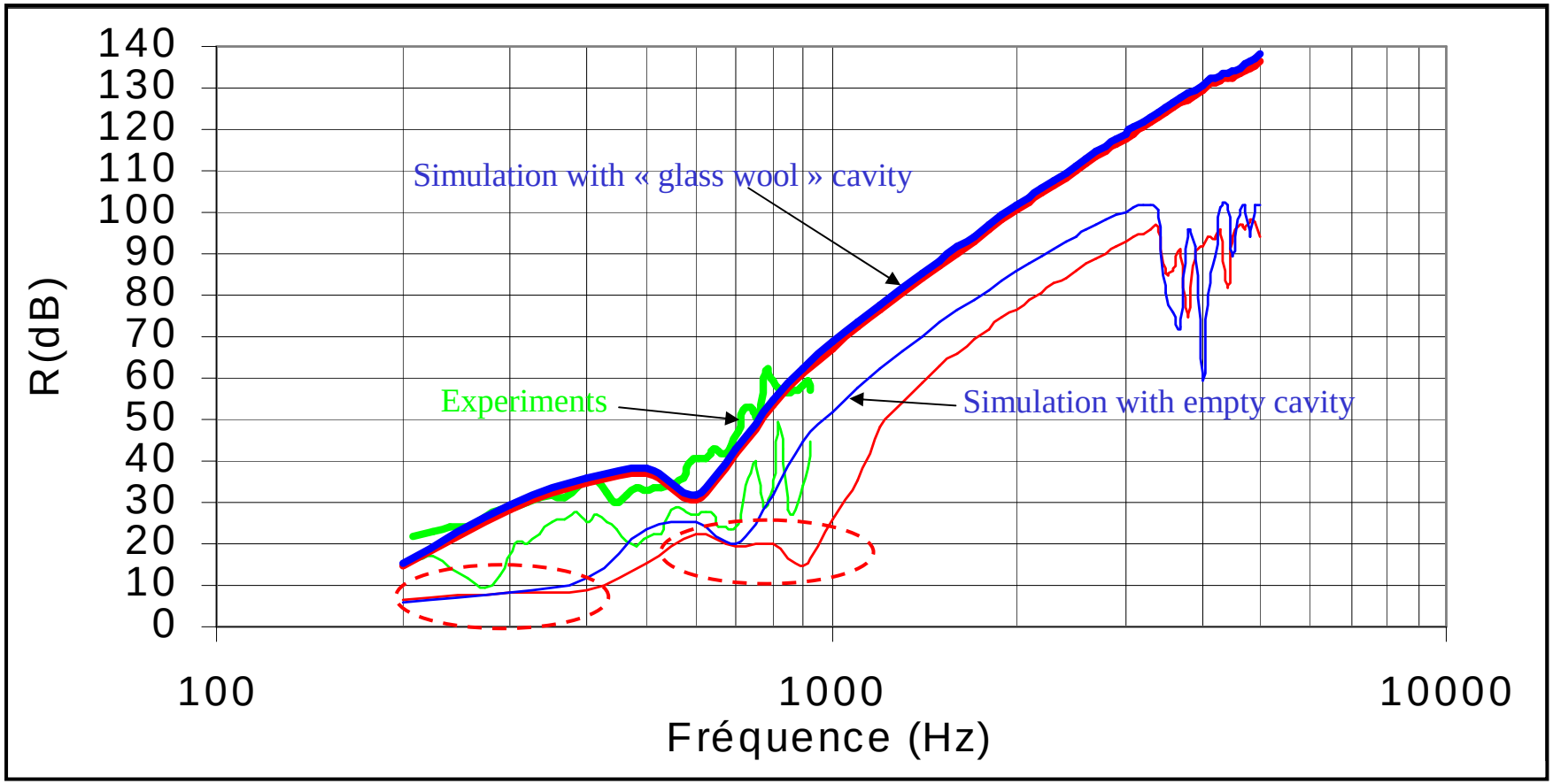
Validation of vibro-acoustic model





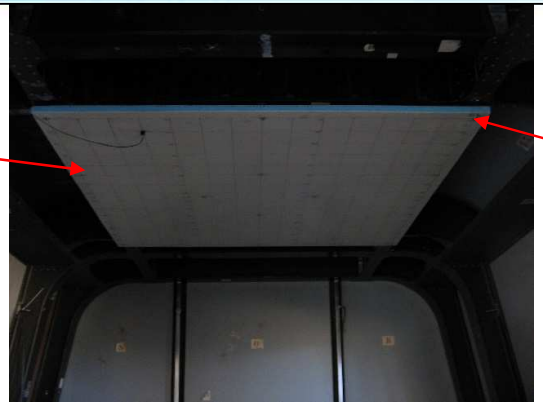


Validation of vibro-acoustic model

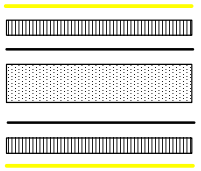


Acoustic Transmission Loss (dB)

ONERA Mock-up (VASCo) with roof trim panel

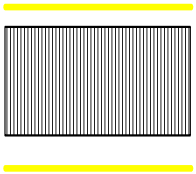


14 viscoelastic mounts



22 mm - 5.2 kg/m²

« Foam » trim panel



20 mm - 6 kg/m²

« Honeycomb » trim panel

Experimental Insertion Loss (dB) up to 3 kHz:

- « foam » trim panel: 35-40 dB
- « honeycomb » trim panel: 15-20 dB

Actually : Helicopter GARTEUR group (Onera, DLR, NLR, Microflown, Univ. Polimi) relative to “Design and characterization of composite trim panels”

Conclusion

New idea of porous solutions and dedicated measurement techniques for exterior or interior noise are welcome to satisfy (future) industrial requirements and improve knowledge !

The demand is strong and possibilities are endless if the industrials accept to dream !

Thank you for your attention