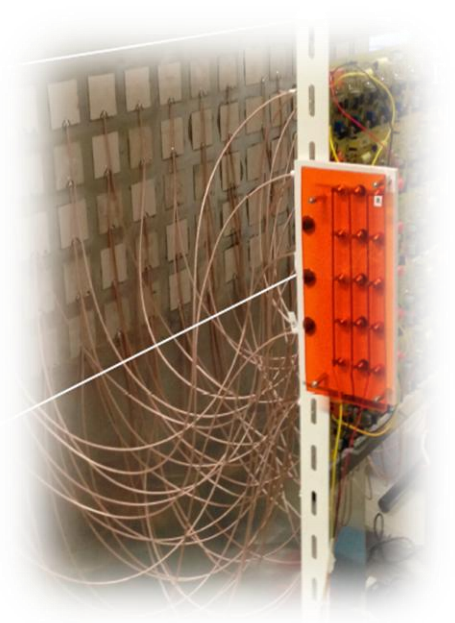
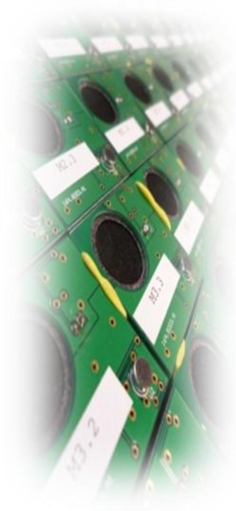


Control strategies for a distributed, active, acoustic skin



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Prof. Manuel COLLET (CNRS, FR)
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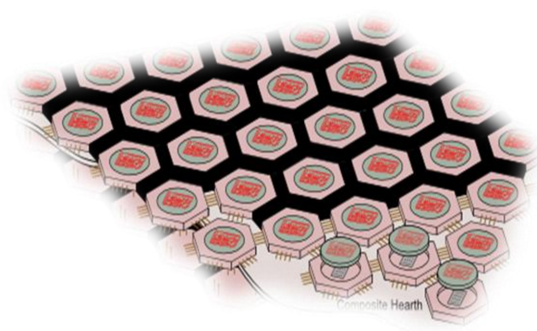


9-12 August 2015
inter.noise 2015
San Francisco, California USA

Context

- EU research and innovation strategy for aviation (ACARE)

  ACARE — Advisory Council for Aviation Research and Innovation in Europe

- ENOVAL:
  EC-funded research project
  on ultra-high bypass ratio engines

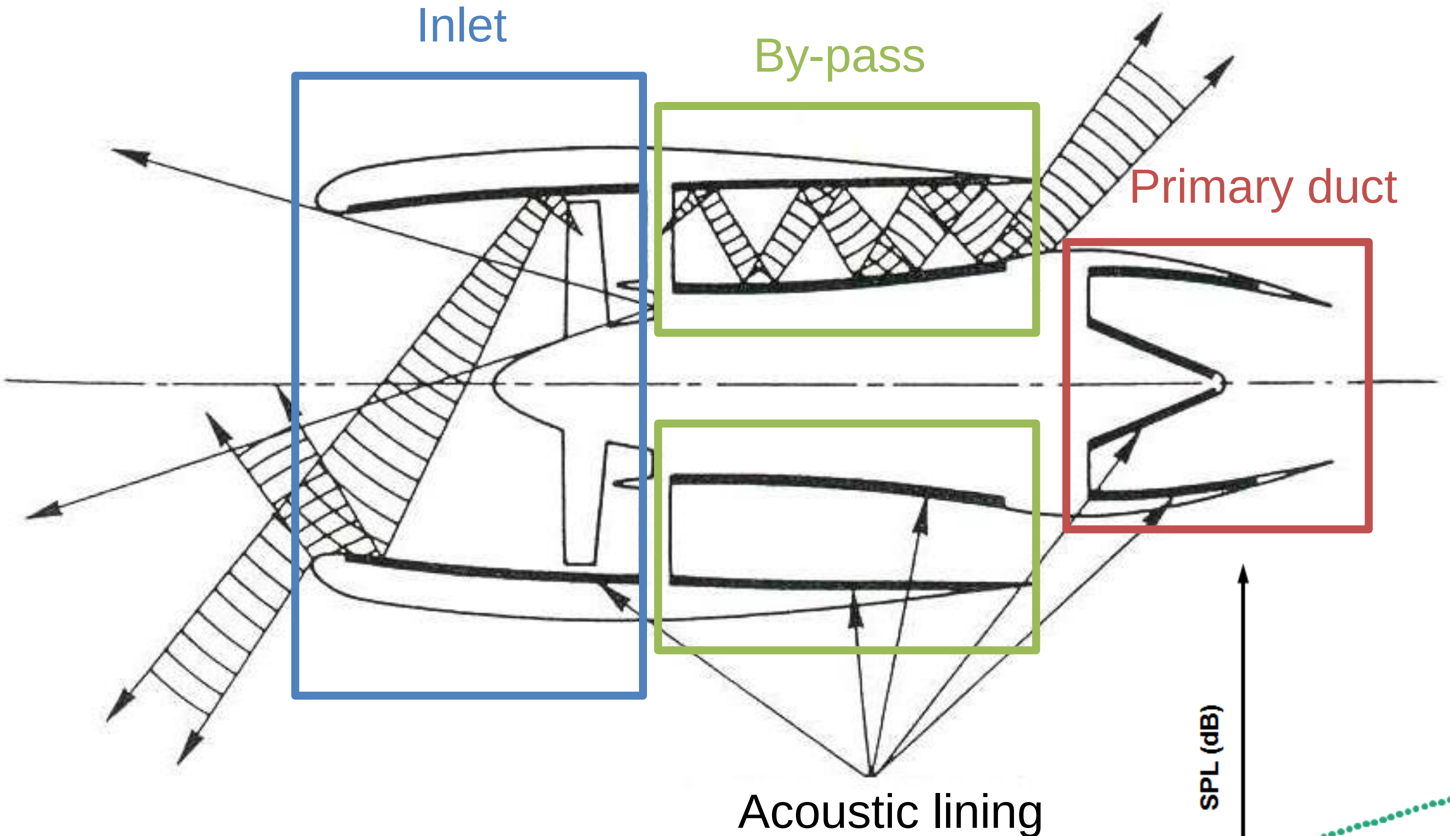
  ENOVAL — Ultra High Bypass Ratio Aero Engines

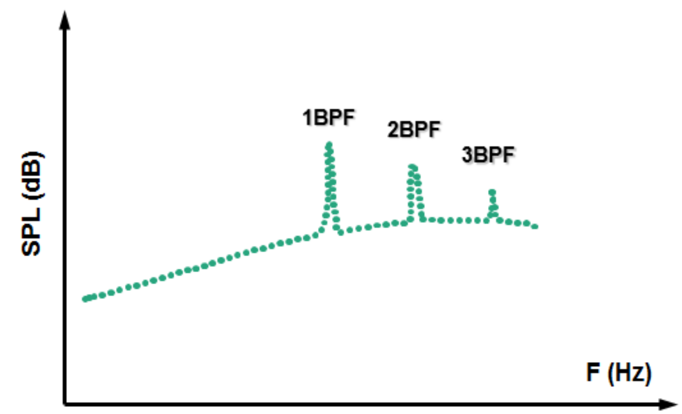
- Goals:
  - Less fuel, less COx/NOx emissions, less *noise*:

➟ **-10dB (-65%) on *perceived* noise level by 2050**
(rel. to year 2000)

(source: ACARE Flightpath 2050)

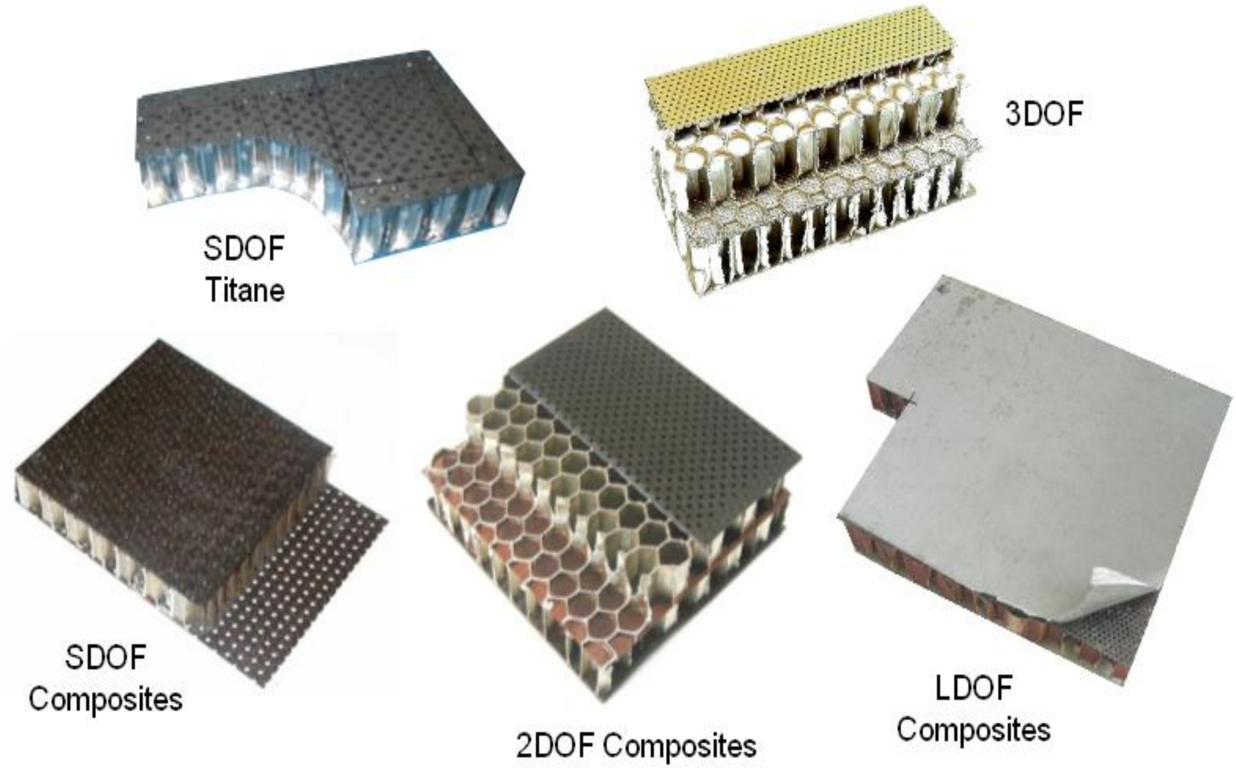
Geared fan noise





State-of-the-art solutions

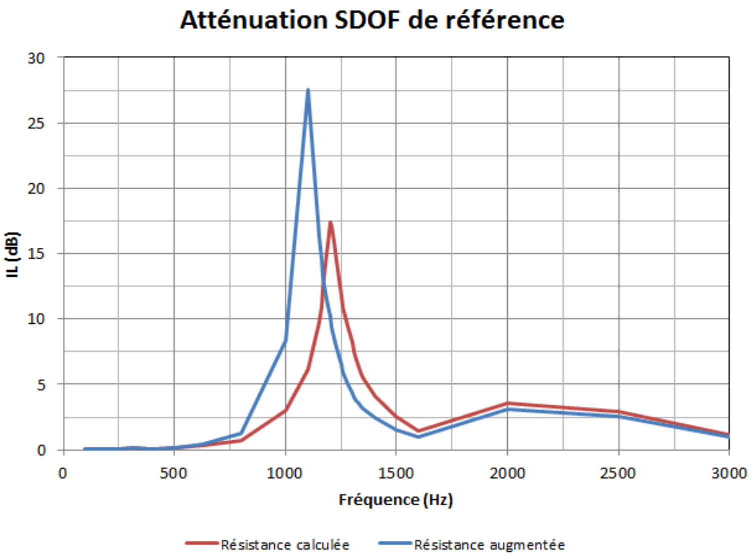
Other passive acoustic linings:



State-of-the-art solutions

Main limitations:

- Narrow bandwidth (Helmholtz resonator)
- Too thick for LF (quarter wave-length)

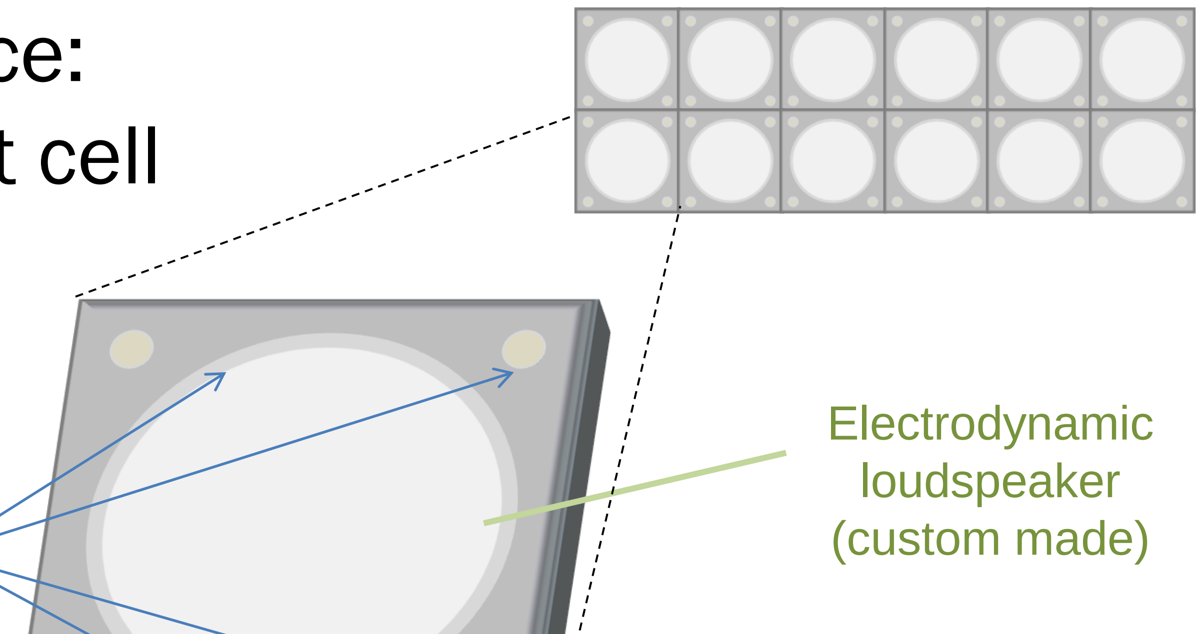


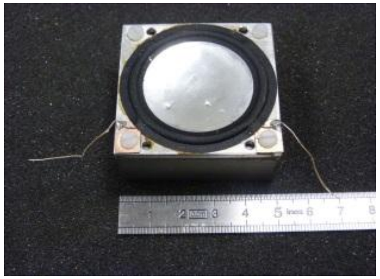
Need for:

- Wideband concept
- Efficient at lower freq.
- Reasonable thickness (50mm)

Proposed active concept

Metasurface:
square unit cell
5x5cm

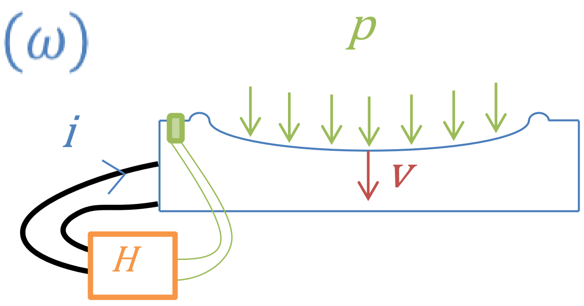




A. Local Impedance control

Each cell is controlled independently

Equation of motion: $Z_m(\omega).v(\omega) = S_d.p(\omega) - Bl.i(\omega)$



Target specific acoustic impedance: $Z_{at}(\omega) = \frac{p(\omega)}{v(\omega)}$

Equation of control: $$H(\omega) = \frac{i(\omega)}{p(\omega)} = \frac{1}{Bl}\left(S_d - \frac{Z_m(\omega)}{Z_{at}(\omega)}\right)$$

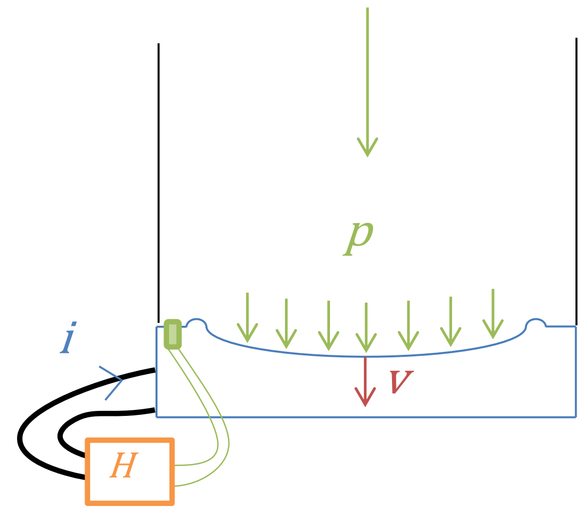
Electroacoustic absorber: EPFL Patent

A. Local Impedance control

Under normal incidence:

Setting target impedance: $Z_{at}(\omega) = \rho c$

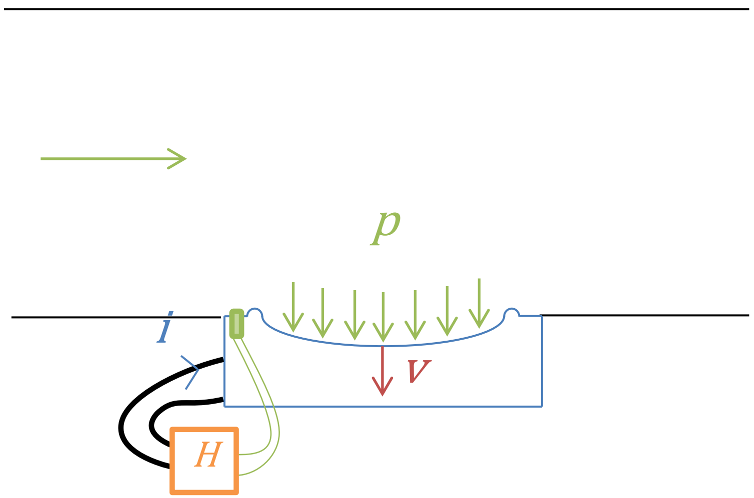
→ Perfect absorption: $\alpha(\omega) = 1$



Electroacoustic absorber: EPFL Patent

A. Local Impedance control

Under grazing incidence:



Optimal target impedance obtained through optimization (numerical simulations):

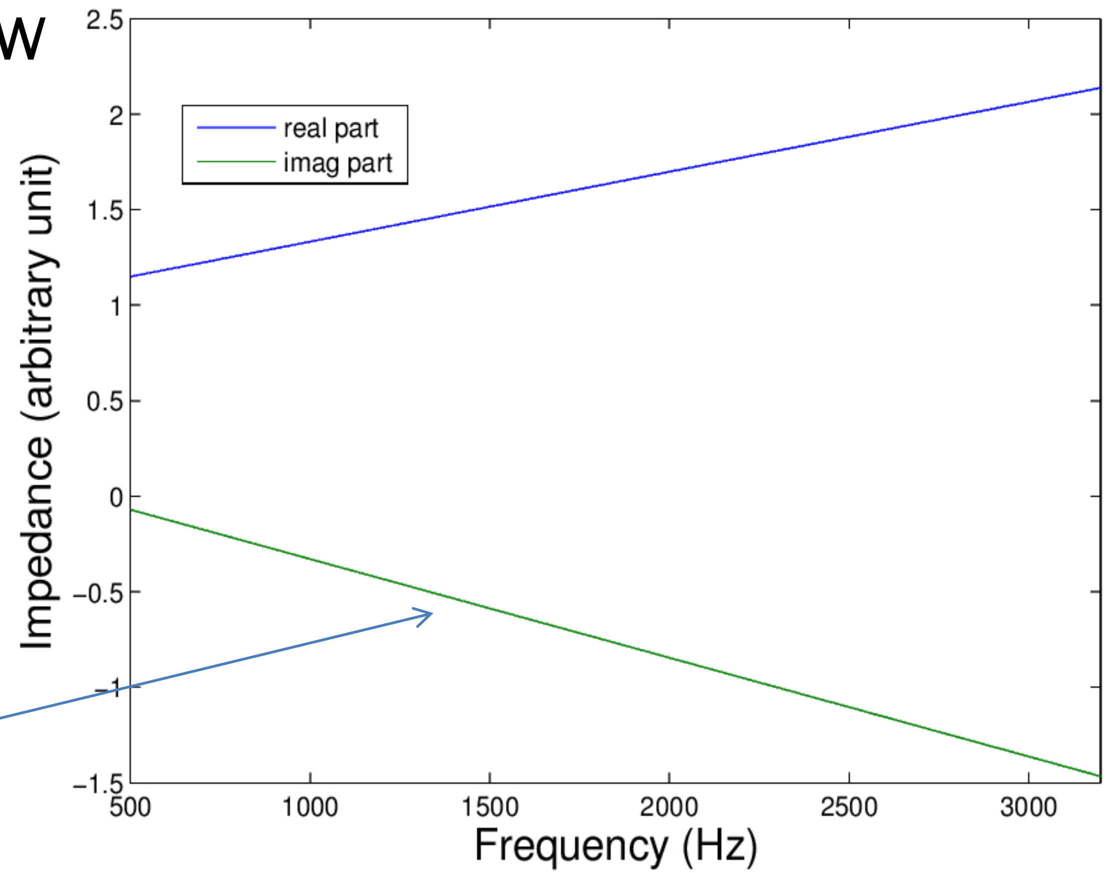
$$Z_{at}(\omega) = re(\omega) + \mathbf{i}\; im(\omega)$$

→ Maximum Insertion Loss

A. Local Impedance control

Tube with grazing flow

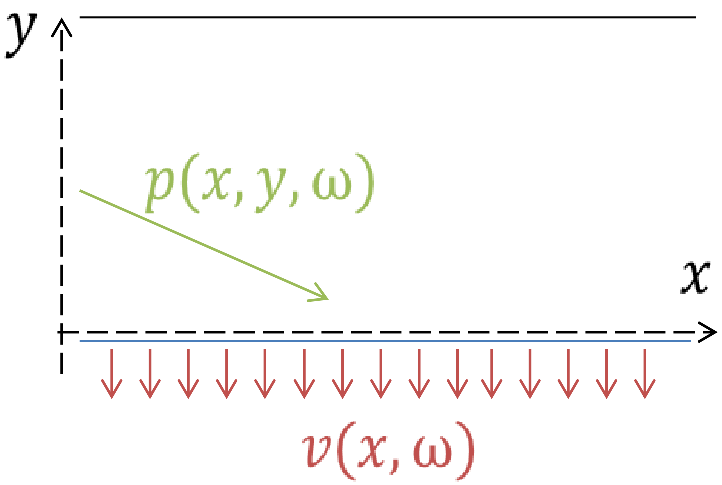
Optimal target impedance:



! Not easily realizable

B. Distributed control

Wave propagation eq.: $(\Delta + k^2)p(x,y,\omega) = 0$

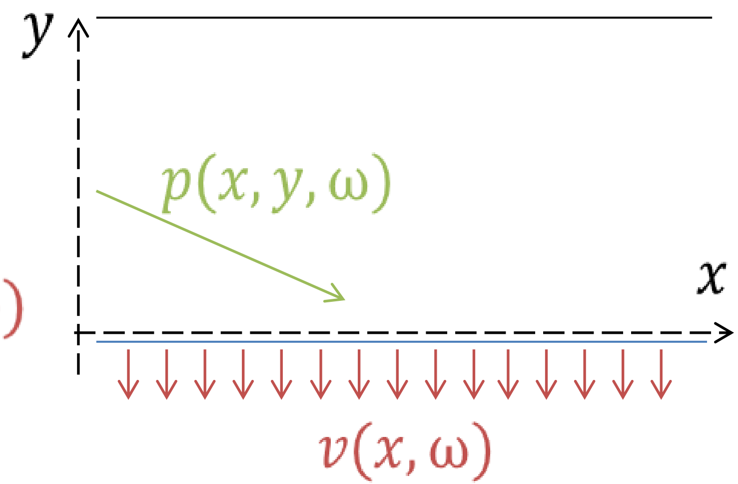


Collet et al., JASA 2009

B. Distributed control

Wave propagation eq.: $(\Delta + k^2)p(x, y, \omega) = 0$

Boundary condition: $\frac{\partial p}{\partial y}(x, 0, \omega) = -j\omega\rho v(x, \omega)$



Collet et al., JASA 2009

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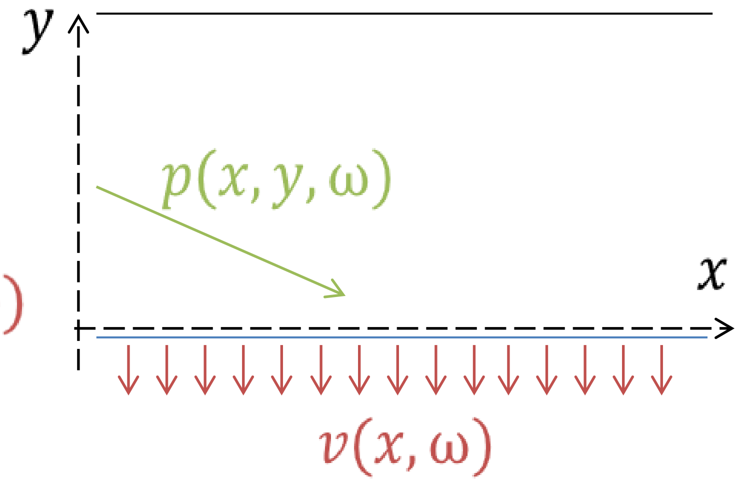


Control law: $$-j\omega\rho v(x,\omega) = -\left(\frac{j\omega}{c_a}p(x,0,\omega) - \frac{\partial p}{\partial x}(x,0,\omega)\right)$$

→ Evanescent waves toward $x > 0$

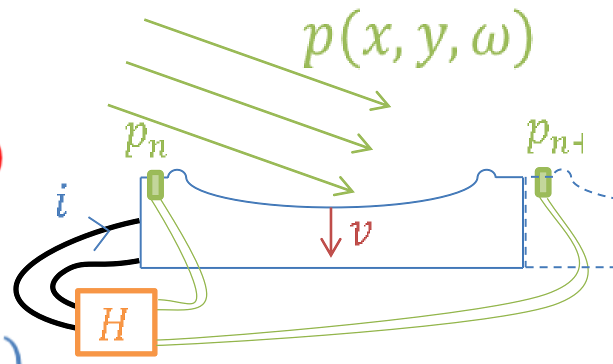
Collet et al., JASA 2009

B. Distributed control

Target "impedance": $v(\omega) = \frac{1}{\rho c_a} p(\omega) - \frac{1}{j\omega\rho} \frac{\partial p}{\partial x}(\omega)$

Local impedance $Z_{loc}(\omega)$

Distributed impedance $Z_{dis}(\omega)$



Equation of motion: $Z_m(\omega).v(\omega) = S_d.p(\omega) - Bl.i(\omega)$

B. Distributed control

Target "impedance": $v(\omega) = \frac{1}{\rho c_a} p(\omega) - \frac{1}{j\omega\rho} \frac{\partial p}{\partial x}(\omega)$

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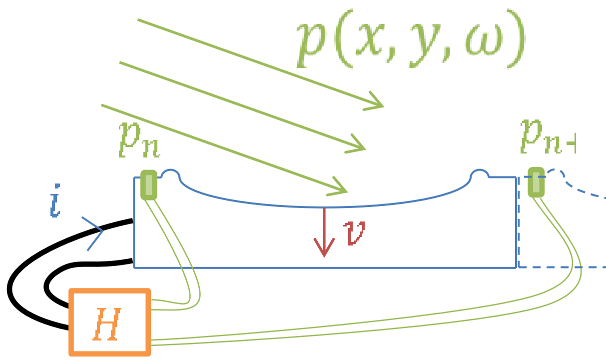


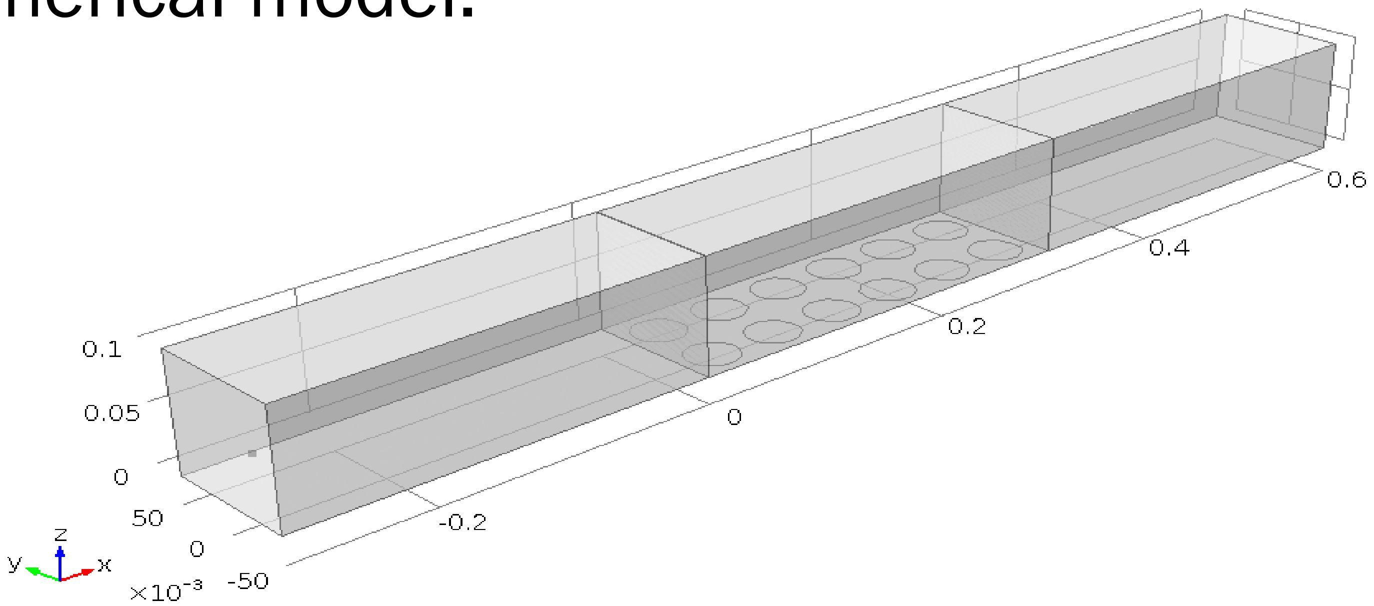
Equation of control:

$$i(\omega) = H_{loc}(\omega)\frac{p_{n+1}(\omega) + p_n(\omega)}{2} + H_{dis}(\omega)\frac{p_{n+1}(\omega) - p_n(\omega)}{\Delta x}$$

$$H_{loc}(\omega) = \frac{1}{Bl}\left(S_d - \frac{Z_m(\omega)}{Z_{loc}(\omega)}\right) \qquad H_{dis}(\omega) = \frac{Z_m(\omega)}{Bl\, Z_{dis}(\omega)}$$

C. Results

Numerical model:



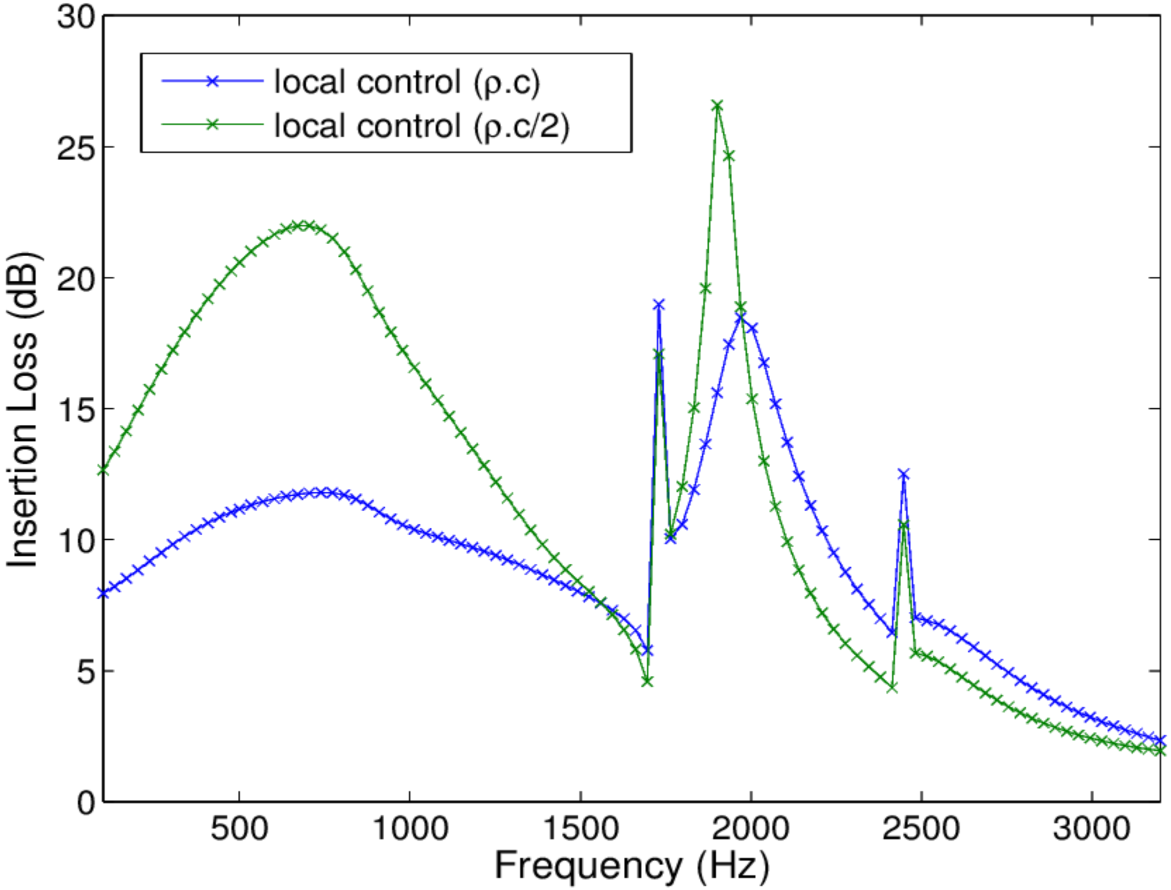
6x2 cells paving a duct wall

C. Results

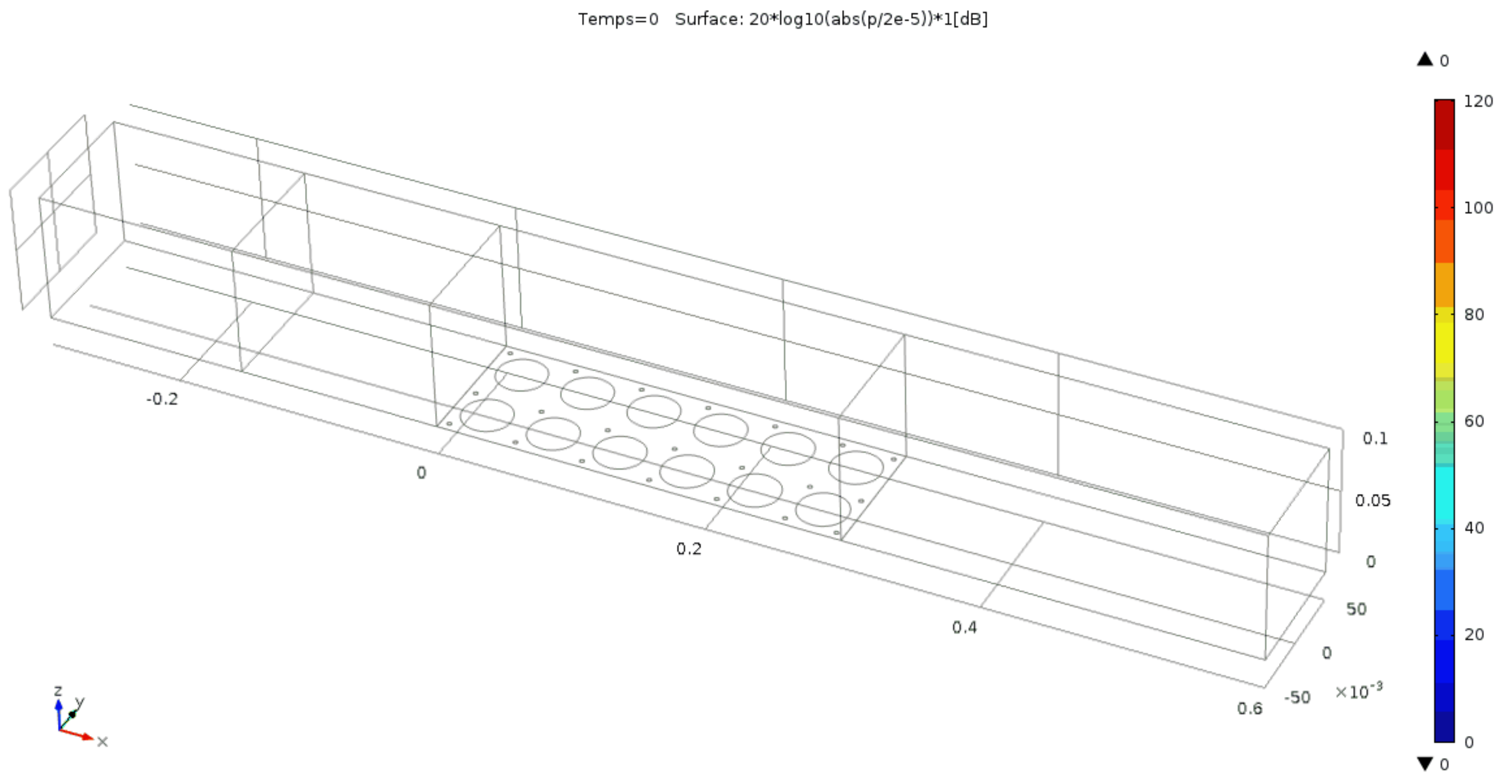
Local control:

Target impedance (without flow):

- ρc
- $\rho c/2$



C. Results



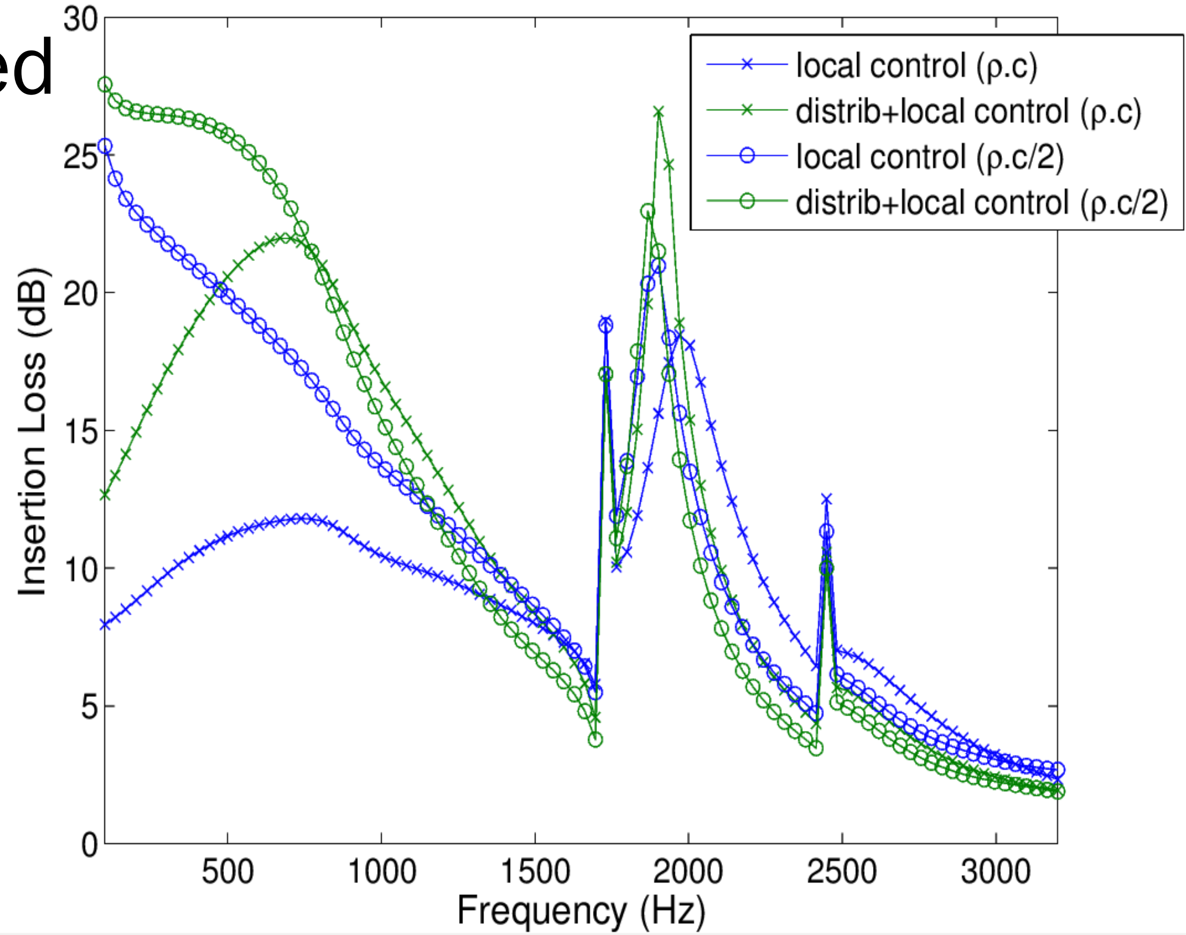
Temps=0 Surface: 20*log10(abs(p/2e-5))*1[dB]
▲ 0
120
100
80
60
40
20
0
▼ 0
-0.2
0
0.2
0.4
0.6
0.1
0.05
0
50
0
-50
×10⁻³
z
y
x

C. Results

Local vs. distributed

$$Z_{loc}(\omega) = \rho c \text{ or } \rho c/2$$

$$Z_{dis}(\omega) = j\omega\rho$$

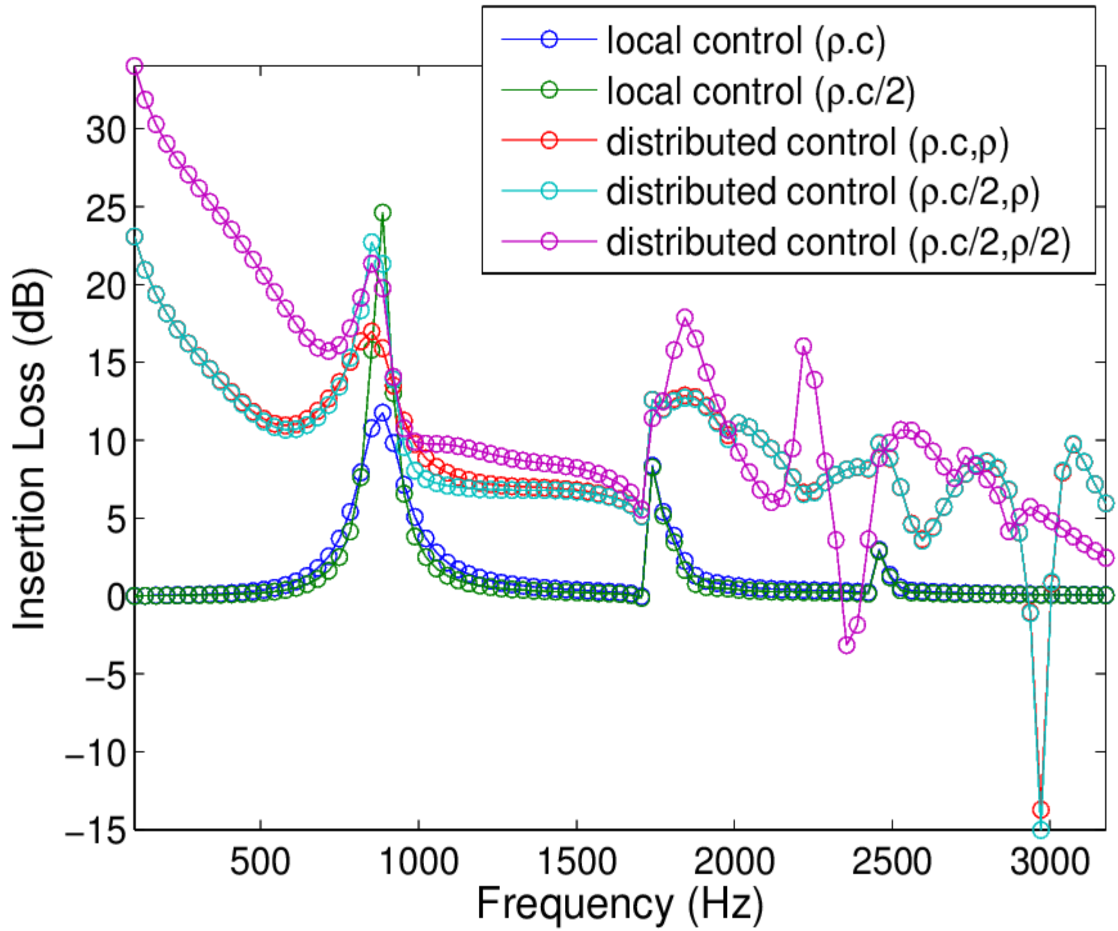


C. Results

Realistic control:
band-pass filtered

$Z_{loc}(\omega) = (\rho c$ or $\rho c/2).BP(\omega)$

$Z_{dis}(\omega) = j\omega\rho$ or $j\omega\rho/2$



Conclusions

- It works! max(IL)>30dB
- Local control might be too narrow band
  (depends on: actuators, stability of the setup…)
- Distributed control allow for wideband control
  (especially LF)
- Experiments under way
  (preliminary results confirm simulations on local control)

Prospects

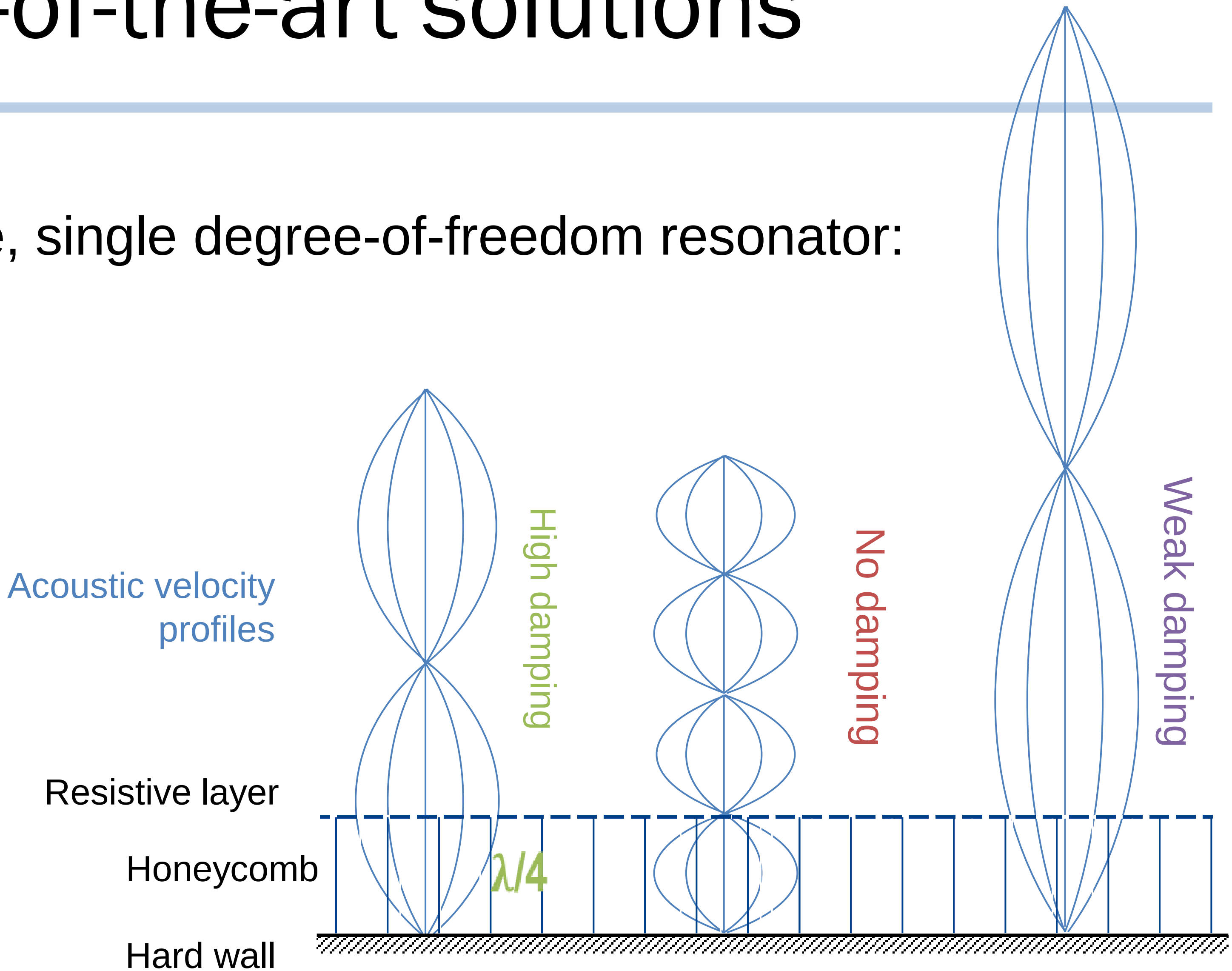
- Adaptive law for local control
  (matching the BPF with the resonance…)
- Investigating stability issues
  (e.g. how to take into account mutual coupling)
- Scale up the experiment for tests in a flow duct
  (NLR, 2016)

THE END

THANK YOU

State-of-the-art solutions

Passive, single degree-of-freedom resonator:



Active solution: ANC

Multichannel ANC:
- efficient (on-axis, at least)
- potentially broadband

BUT

- computationally intensive
  (with lots of sensors/actuator)
- based on energy reinjection
  (heavy weight, energy costs, spill over…)

New concept: smart materials

- sub-wavelength architecture
- distributed systems with lots of actuators
- adaptive, sensorless concepts
- semi-active concepts (absorption, redirection of energy)

→ Engineered (apparent) material properties
→ Exotic boundary conditions