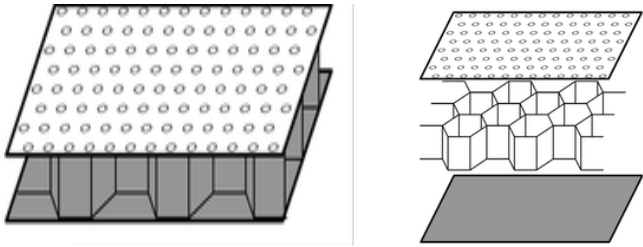


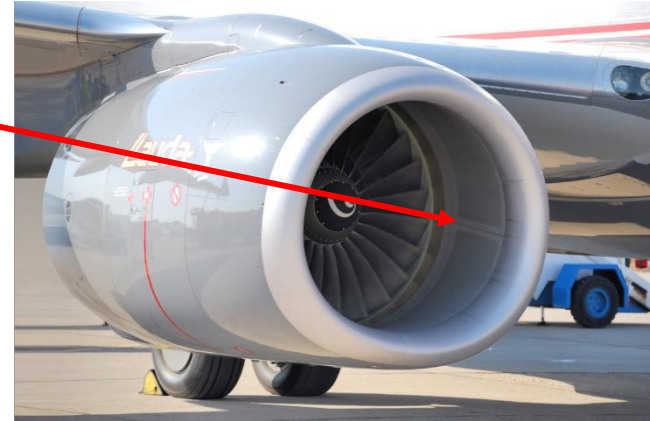
MAINE FLOW

**EXPERIMENTAL FACILITY FOR CHARACTERISATION OF
LINERS SUBJECTED TO REPRESENTATIVE ACOUSTICAL
EXCITATION AND GRAZING FLOW**

**J. GOLLIARD, E. PORTIER, J.C. LE ROUX (CTTM)
PH. HERZOG (ARTEAC LAB)**

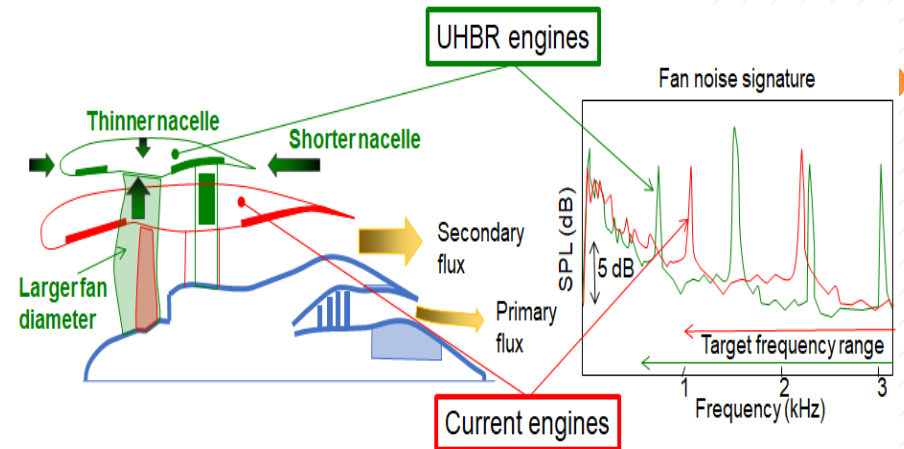


Example of classical treatment
"Single-Degree-of-Freedom liner" (SDOF)

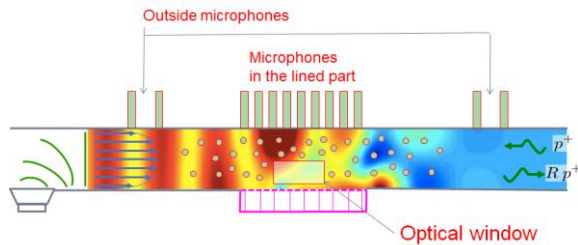
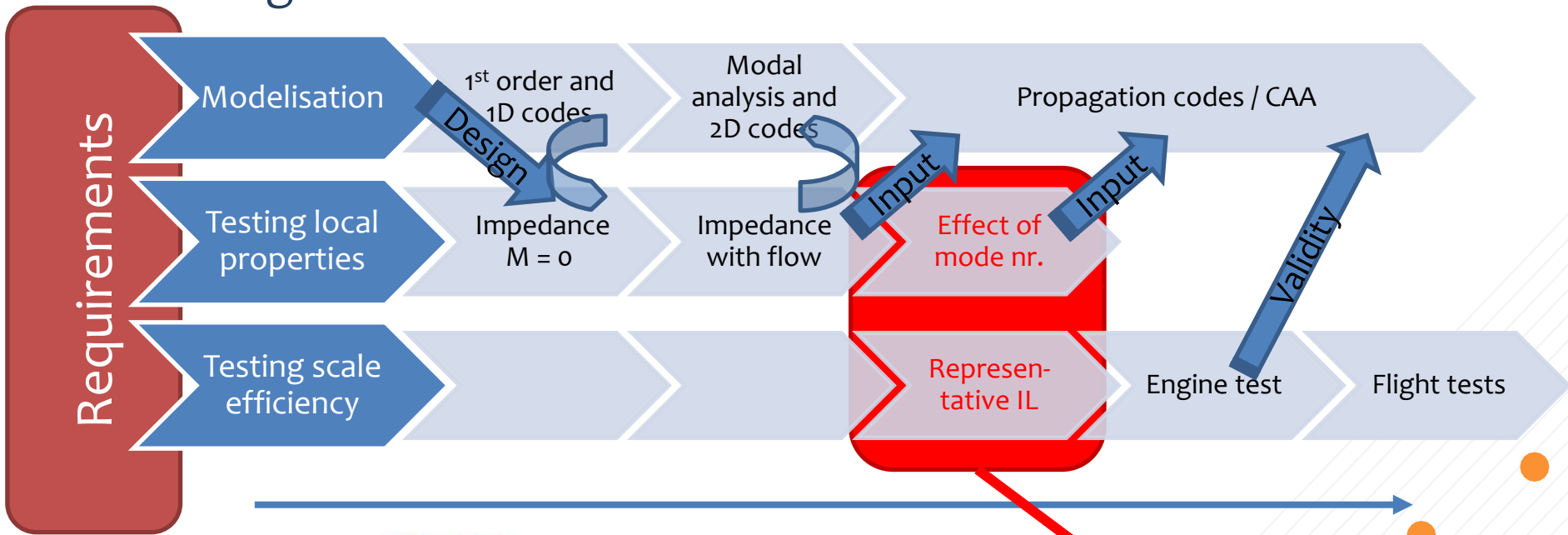


New concepts

- Reduce fuel use: Larger By-Pass Ratio
 - ⇒ Larger fan diameter,
 - ⇒ Thinner and shorter nacelle
 - ⇒ Lower rotation speed
 - Mostly good for noise emissions, but...
 - Requires attenuation at lower frequencies
 - Less space for liners
- ⇒ **Need for new liner concepts with higher acoustic efficiency**

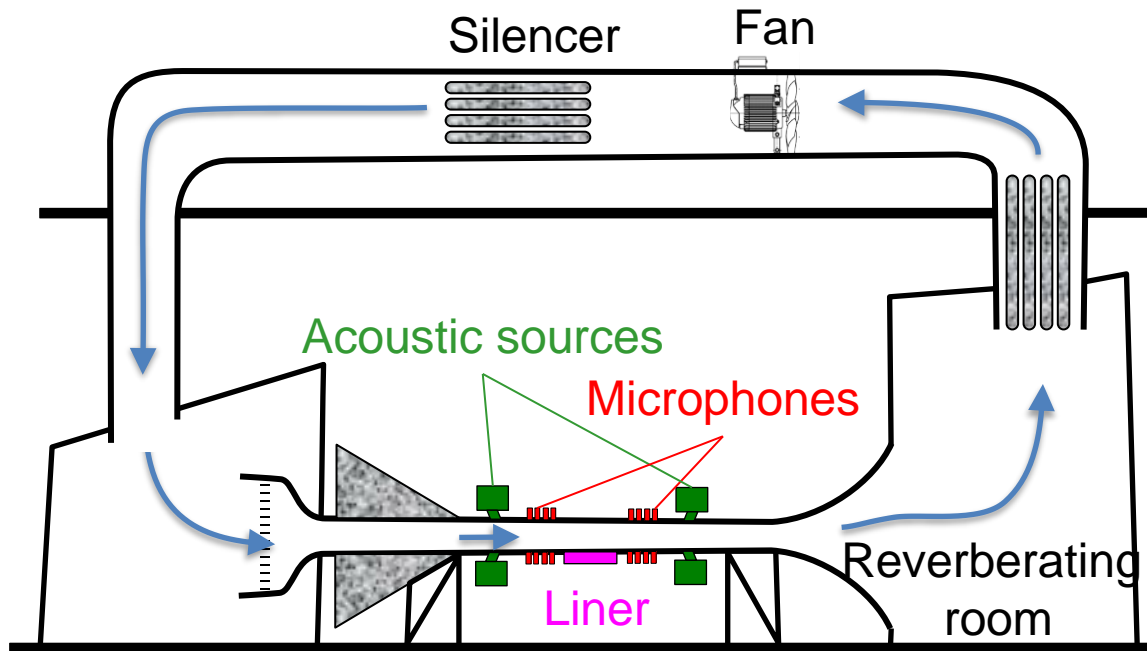


- Design process: How are acoustic liners selected and qualified for an engine & nacelle?



Grazing or orthogonal plane wave

Need of a new facility to bring new insights and more trust in the design process

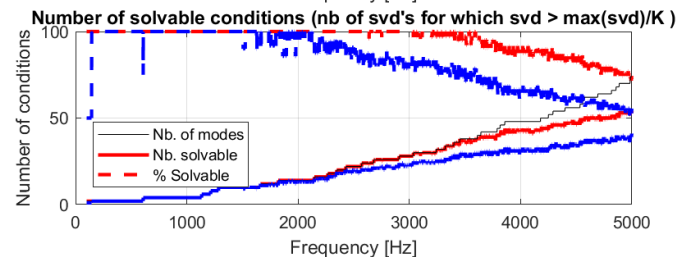
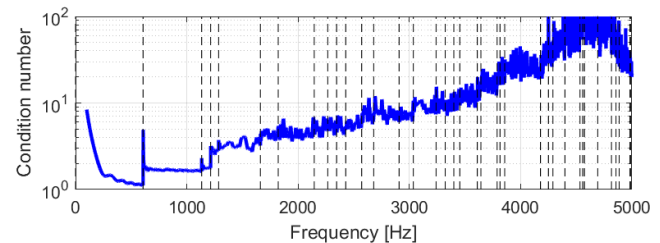
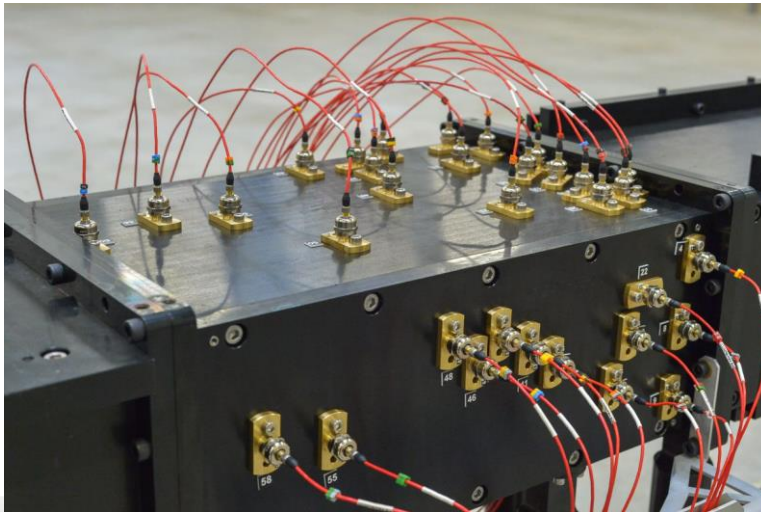


Section	280 × 150 mm ²
Mach	0.6
SPL	150 dB
Multi-Modal excitation	
Frequencies	400 Hz– 5 kHz
Meas.	<ul style="list-style-type: none"> - Insertion Loss - Scattering Matrix - In-situ Z - KT ? - Optical ?

Expected Output:	Impedance for each acoustic mode (Not only up-/downstream directions)
	Insertion Loss with controlled modal content

Le Mans University is the owner of the test bench

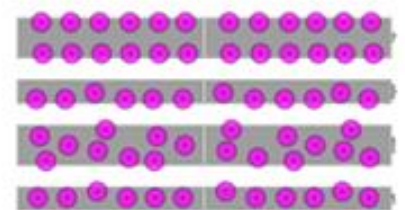
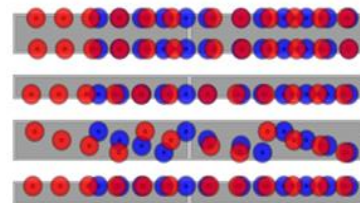
- Allow modal decomposition of acoustic field in the duct
- Position optimisation principle:
 - Logarithm distribution in axial (x) direction
 - "Random" distribution on y and z directions
 - Repeat the draw until the condition number doesn't improve any more

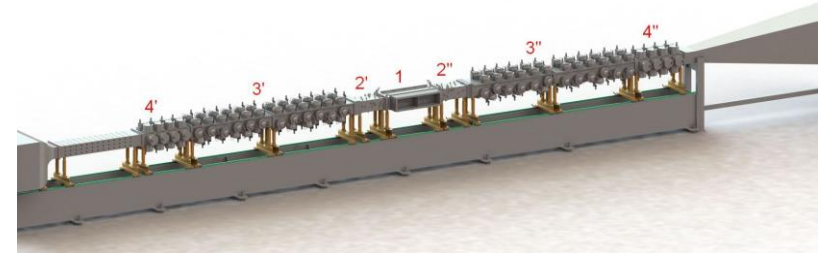
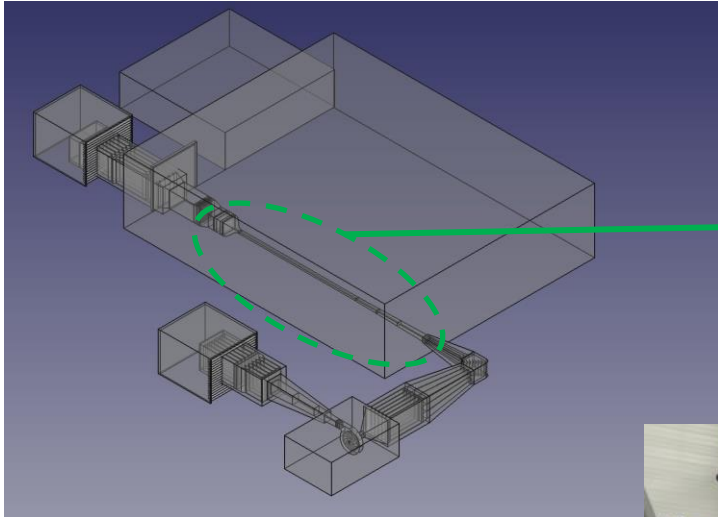


- Main challenges :
 - Sufficient acoustic power for a large cross section:
 - Several modes to be controlled (≈ 30 modes at 5 kHz)
- => Large number of sources



- Final structure
 - 24 x “low frequency drivers” :
 - Plane mode only (300Hz – 1kHz)
 - One channel for 6 drivers
 - 66 x 2” compression drivers
 - All modes (600Hz – 5kHz)
 - One driver = one channel
 - Optimization of the drivers position on the duct
- => Controlability of each mode





Goal

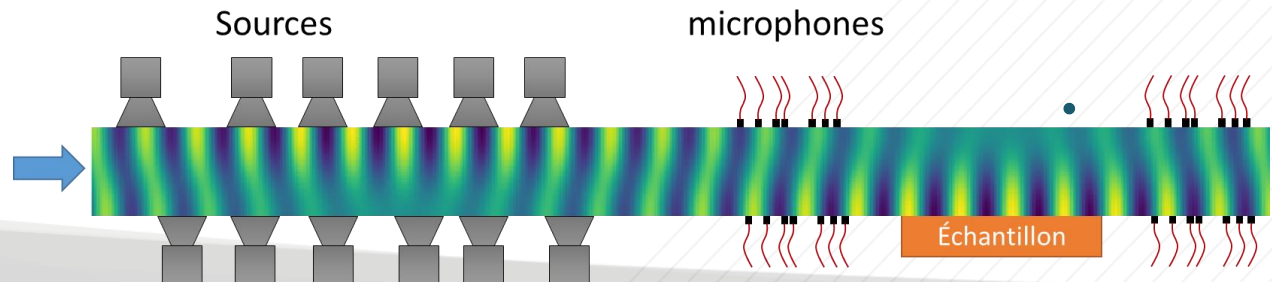
- Be able to force one modal configuration in the duct (one particular mode or a combination of several modes)

Existing device / Constraints :

- Air flow up to 0.6Mach
- Large duct dimensions high number of modes
- HF sources only



Setup optimized for modal control but some hypothesis should be validated



Objective : Linear driving
 \Rightarrow Linear relationship between
 voltage commands and the
 acoustic field in the duct

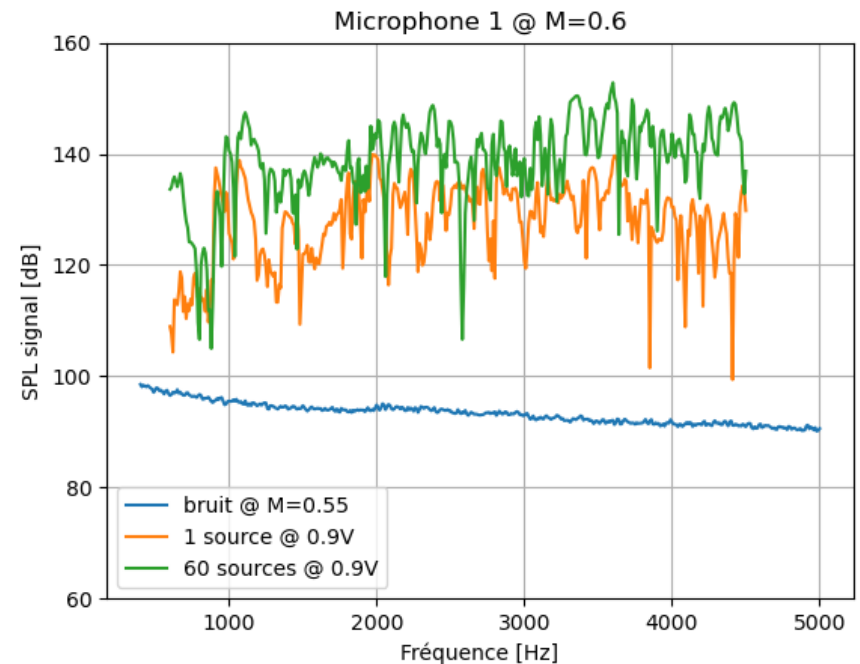
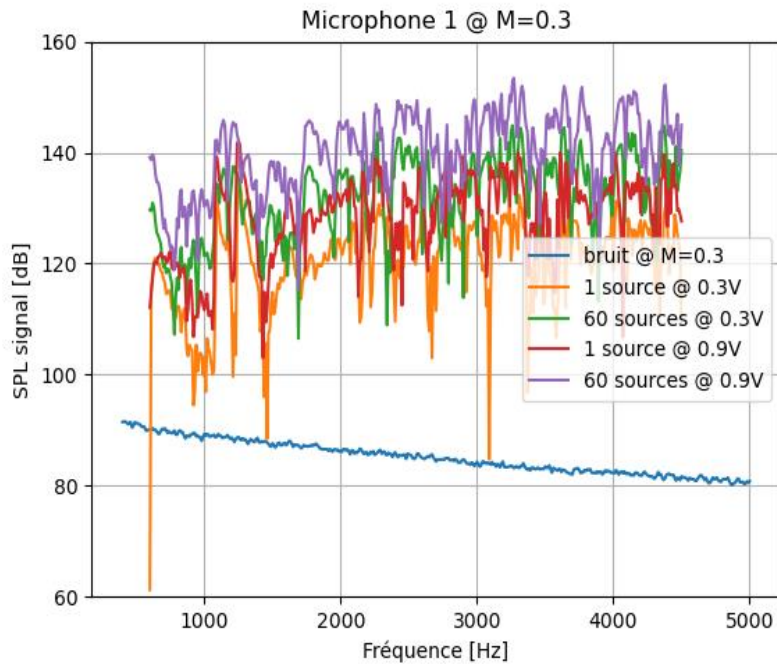
$$\begin{pmatrix} p_{m_1} \\ p_{m_2} \\ \vdots \\ p_{m_N} \end{pmatrix} = \begin{bmatrix} \dots & \dots \\ \vdots & \ddots \\ \dots & \dots \end{bmatrix} \begin{pmatrix} c_{Ch1} \\ c_{Ch2} \\ \vdots \\ c_{ChN} \end{pmatrix}$$

Acoustic propagation : linear

Other requirements:

- Repeatability:
 - No impact of background noise (due to the air flow)
 - Stability of thermodynamic conditions effect on the pressure/command transfer functions
- Linearity (of the sources)
- Superposition principle:
 - No impact of the acoustic field in the duct on the impedance load of each source

Repeatability: impact of background noise



0.3V : nominal driving level

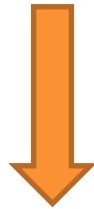
0.9V : max driving level (approx 25Vrms at driver)

Good S/N ratio : > 20dB even with 1 sources, and flow 0.6M

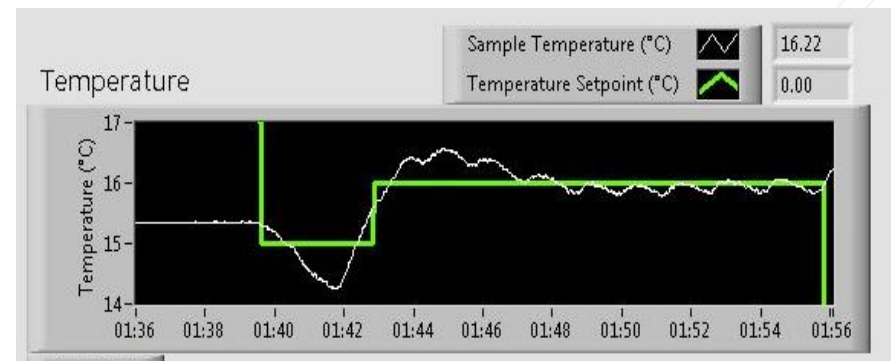
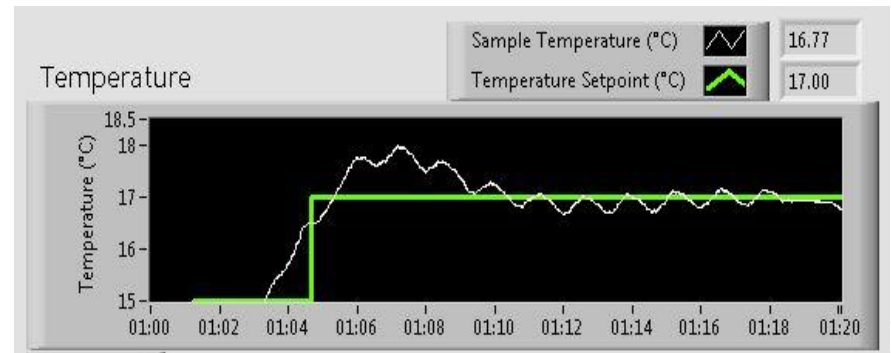
Stability of thermodynamic conditions

TEMPERATURE FLUCTUATION DURING MEASUREMENTS

M = 0.3



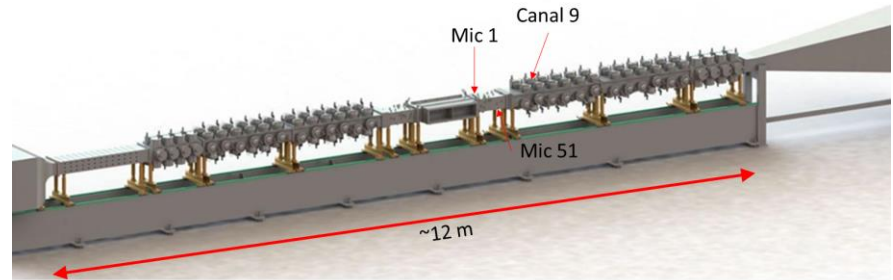
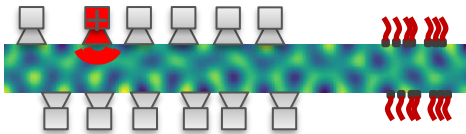
M = 0.6



Very small temperature fluctuations (regulation)
Require to wait before starting the measurement

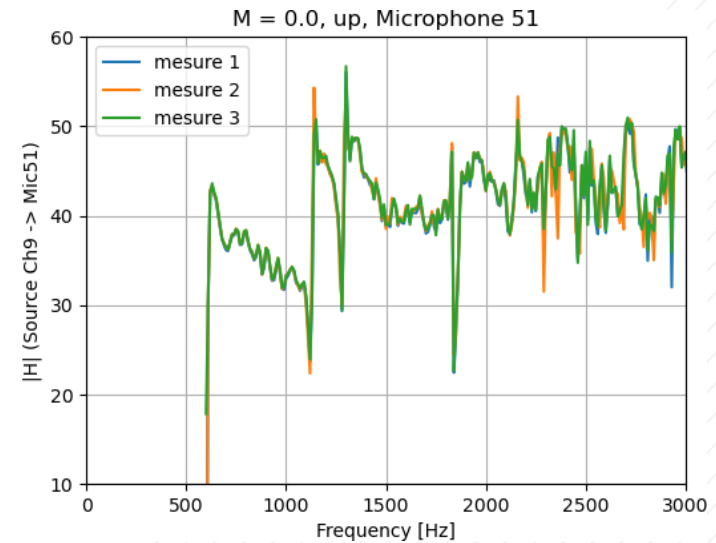
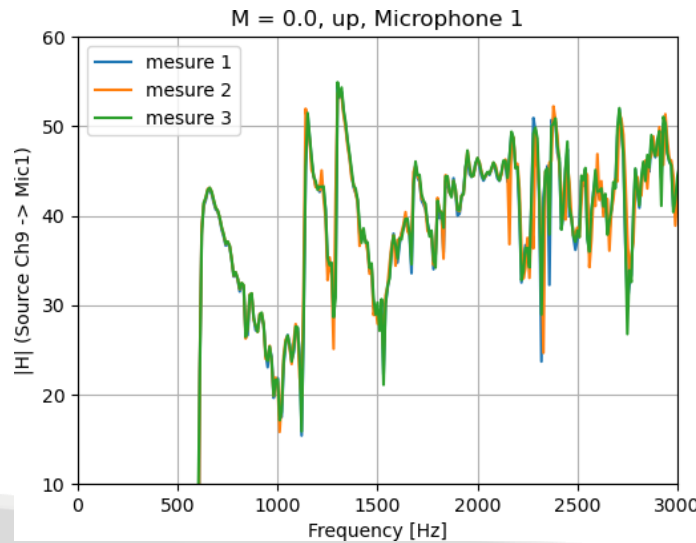
Repeatability / Stability

VOLTAGE COMMAND : SOURCE N°9 ONLY
RECORDED PRESSURE : MIC. 1 AND MIC. 51



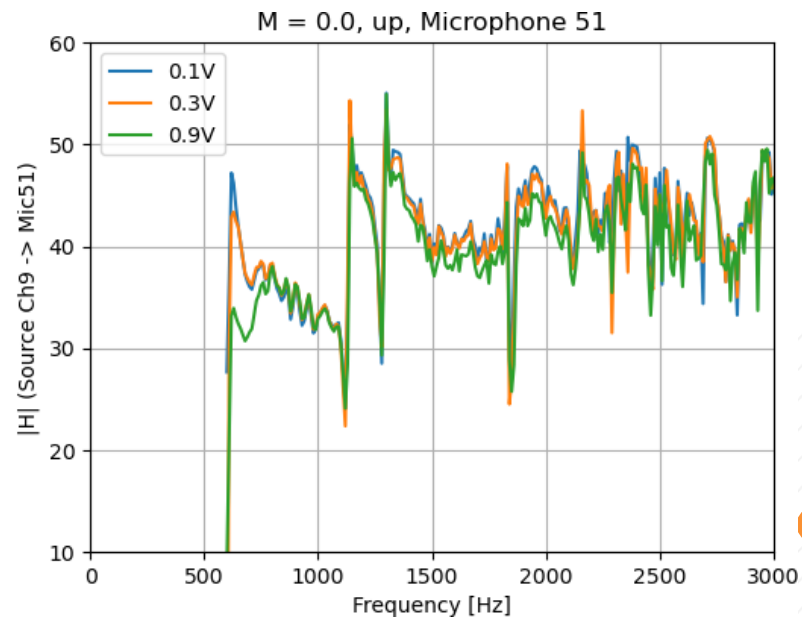
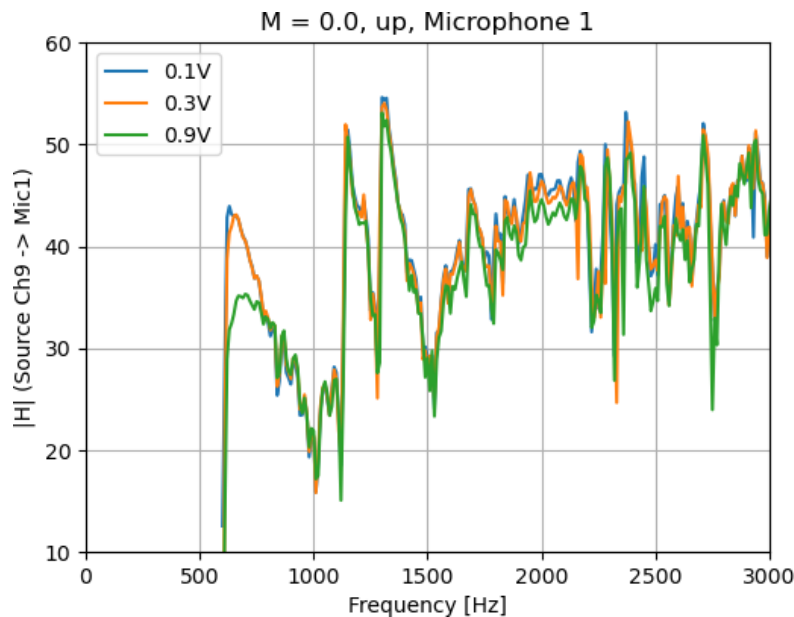
Measurements (without flow):

- Meas 1 : $T = 15.9^{\circ}\text{C}$
- Meas 2 & 3: two days later, $T = 15.3^{\circ}\text{C}$



Sources linearity

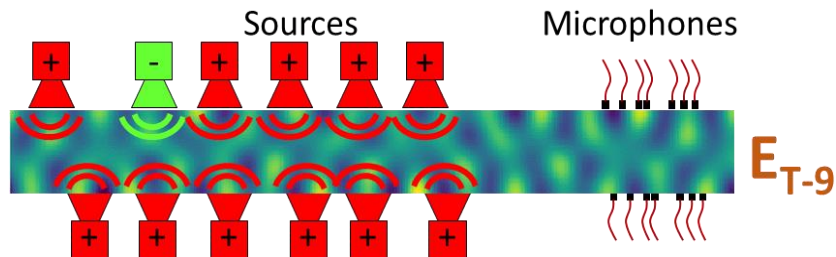
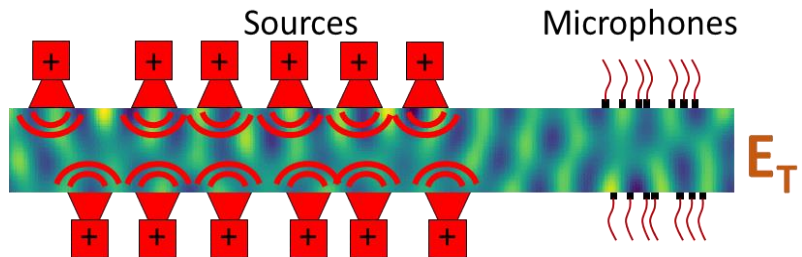
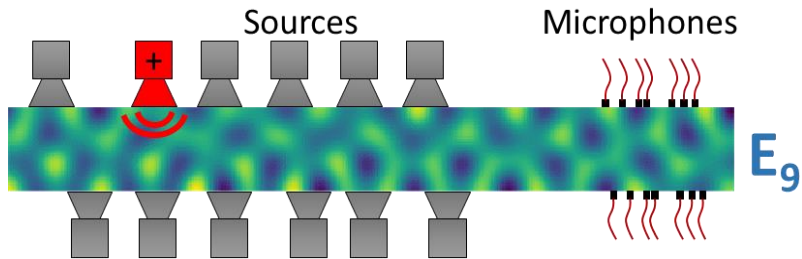
- Source n°9 / mic n°1 and n°51
- Three driving levels (0.9 = max driving level)



- Not really linear at low frequencies (compression driver!), but the sources are never driven at max level in this frequency range (less modes to be controlled, enough level margin)

Small non-linearities in frequency range 1500 – 2200Hz

Superposition principle



E_9 : Canal 9 only

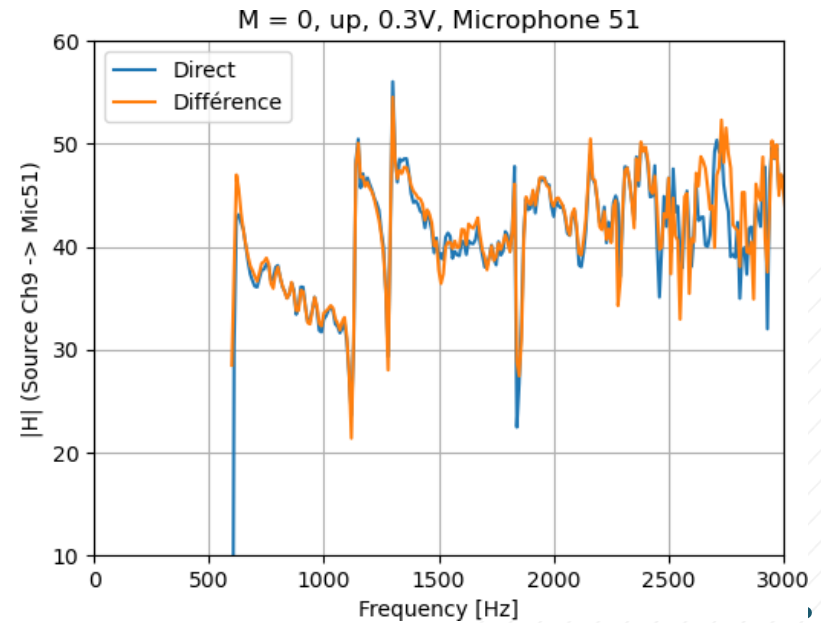
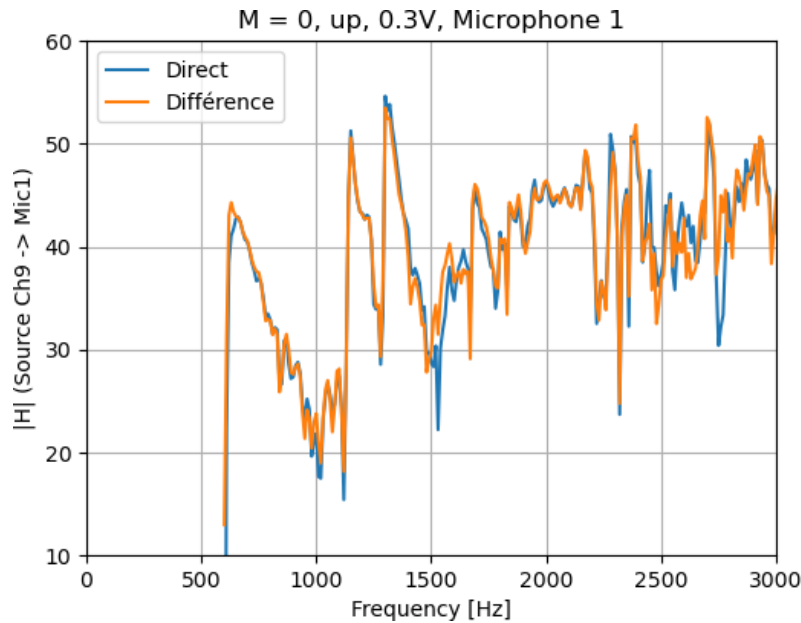
E_T : All sources

E_{T-9} : all sources but canal 9 out of phase

If the superposition principle is valid, at each microphone :

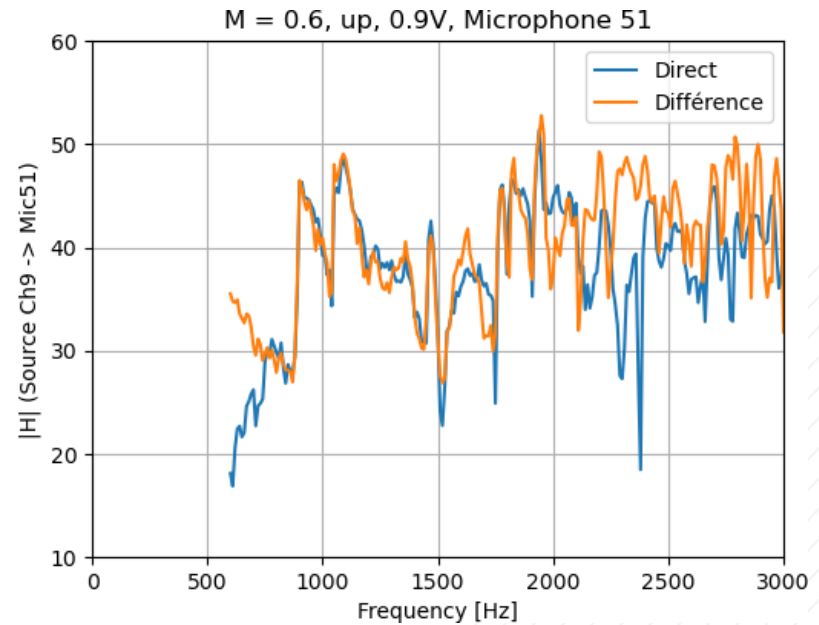
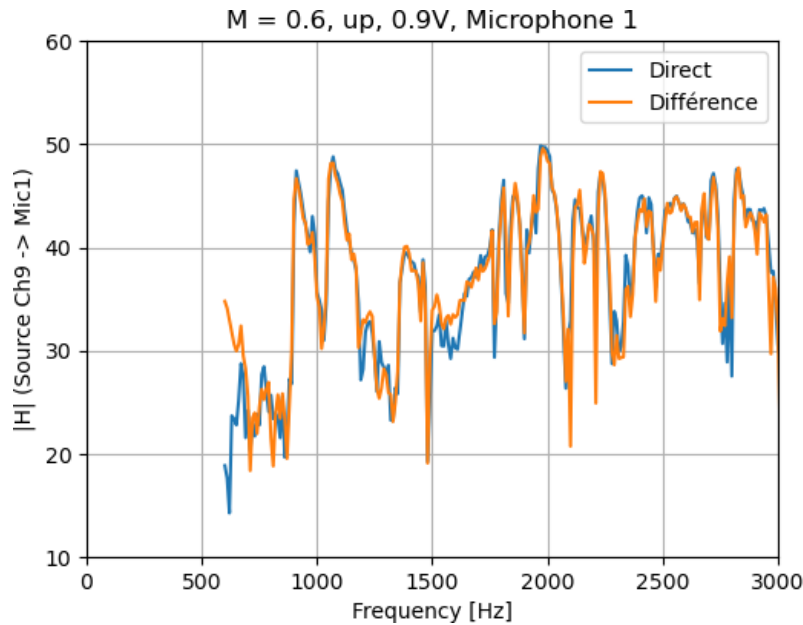
$$P(E_9) = (P(E_T) - P(E_{T-9})) / 2$$

- Measurement without flow
- Nominal driving level



Good results

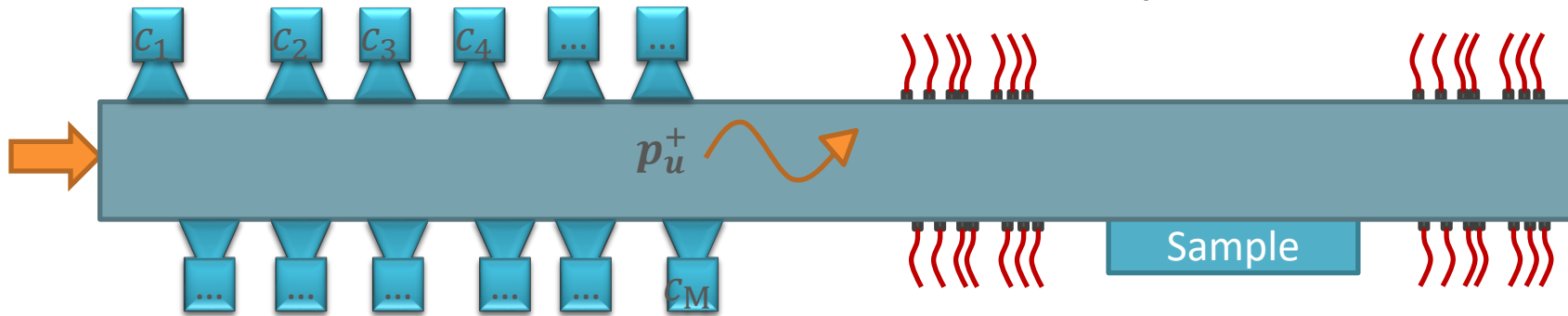
- Measurement with flow (0.6 Mach)
- Max driving level



- Small / acceptable differences, except at very low frequencies
- More noise

Sources

microphones



$$\begin{pmatrix} p_{u1}^+ \\ p_{u2}^+ \\ \vdots \\ p_{uN_{mod}}^+ \end{pmatrix} = \begin{bmatrix} \square & \square & \dots & \square \\ \square & \square & \ddots & \square \\ \vdots & \vdots & \ddots & \vdots \\ \square & \square & \dots & \square \\ \square & \square & \dots & \square \end{bmatrix} \begin{pmatrix} c_{u1} \\ c_{u2} \\ \vdots \\ c_{uN_{chn}} \end{pmatrix}$$

$$\mathbf{p}_u^+ = \mathbf{H}_u \mathbf{c}_u$$

After identification phase, the transfer matrix H_u between source commands and acoustic modes is known

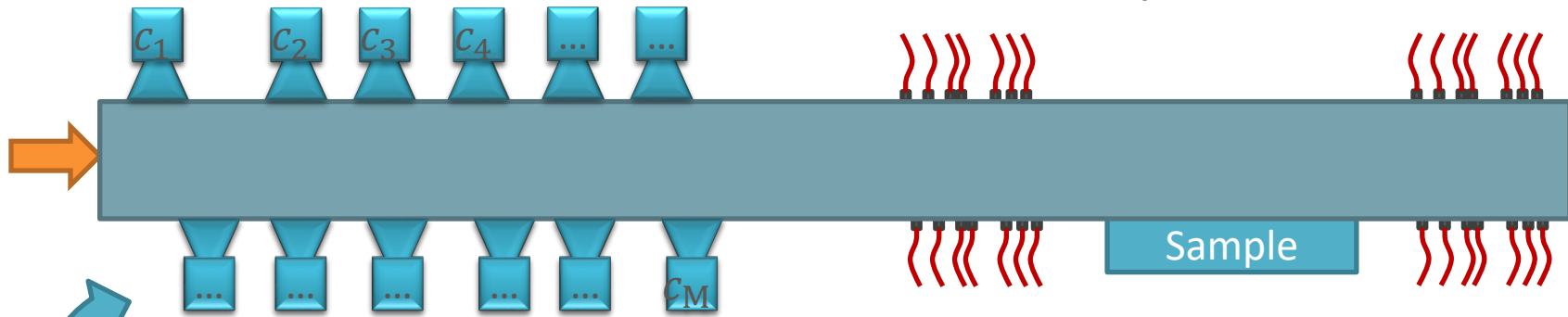
To drive one modal configuration (incident pressure field \mathbf{p}_u^+) we need to determine the command vector \mathbf{c}_u

$$\mathbf{c}_u = \frac{\mathbf{H}_u^*}{(\mathbf{H}_u^* \mathbf{H}_u) + \lambda^2 \mathbf{I}} \mathbf{p}_u^+$$

Pseudo-inversion of the transfer matrix with a penalization factor to limitate voltage command to acceptable magnitude

Sources

microphones



FOR THE FIRST TRANSVERSE MODE

$$\begin{pmatrix} c_{u1} \\ c_{u2} \\ \vdots \\ c_{uN_{chn}} \end{pmatrix} = \frac{H_u^*}{(H_u^* H_u) + \lambda^2 I} \begin{pmatrix} 0 \\ 1 \\ \vdots \\ 0 \end{pmatrix}$$

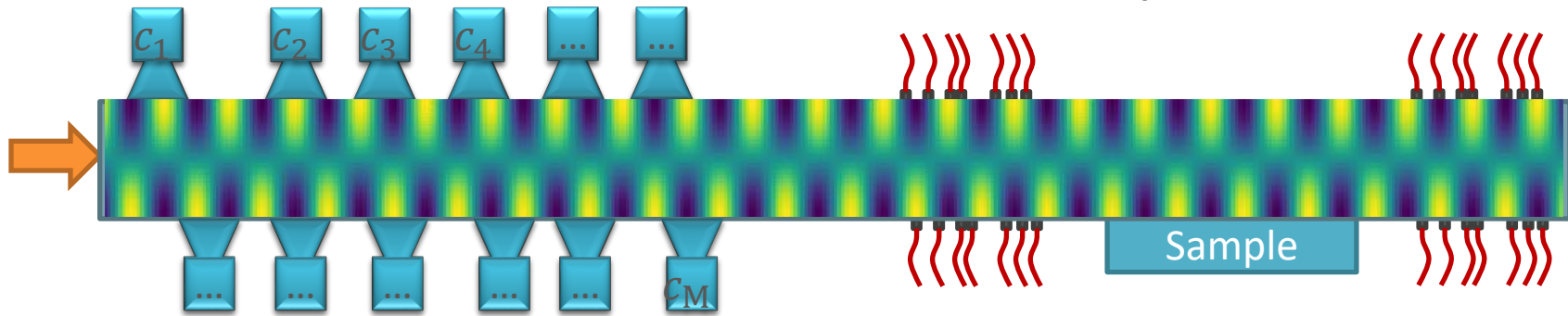


Mode (1,0)

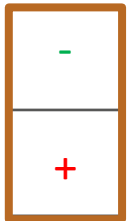


Sources

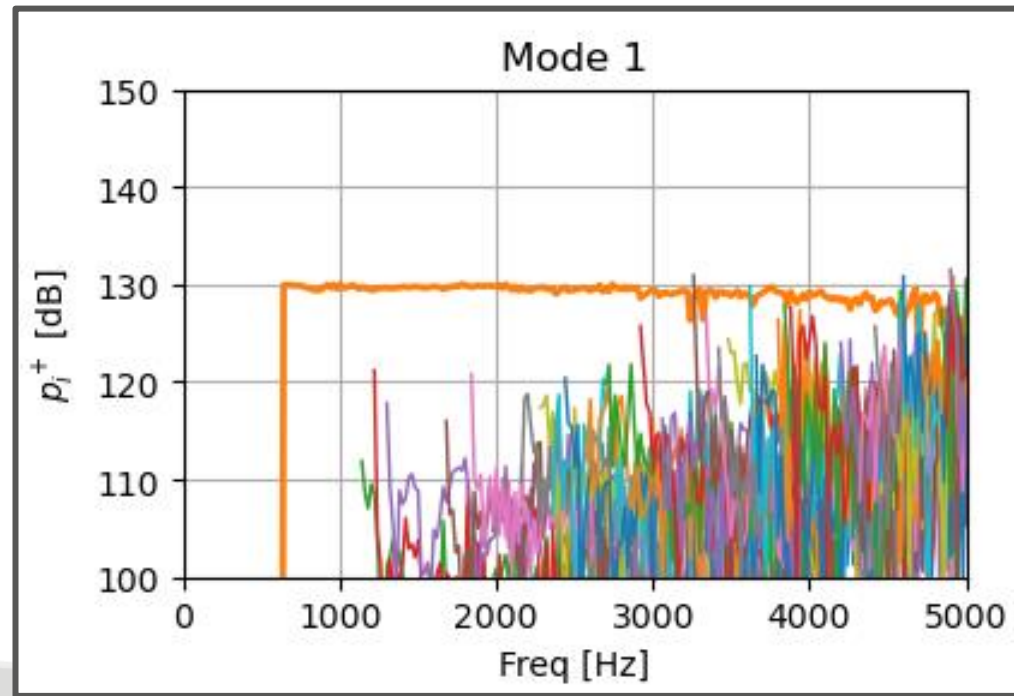
microphones



FIRST TRANSVERSE MODE



Mode (1,0)



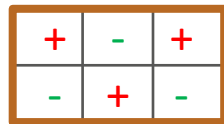
Other results at 0.6 Mach

Mode # 1



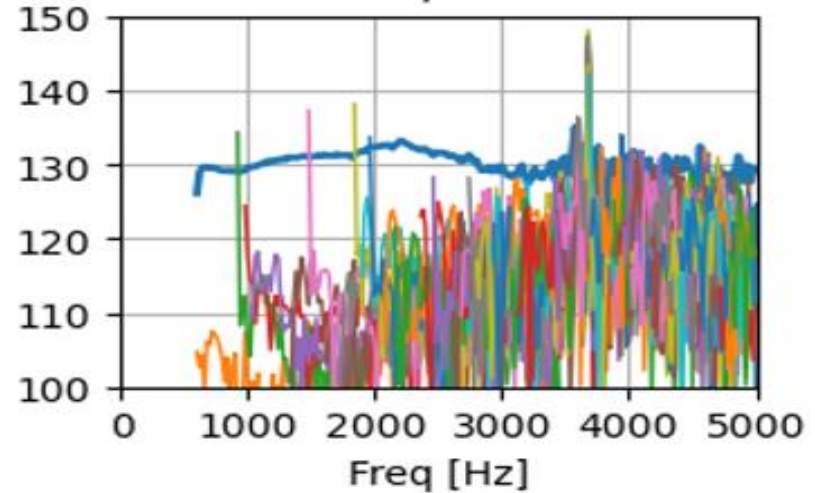
Mode (0,0)

Mode # 5

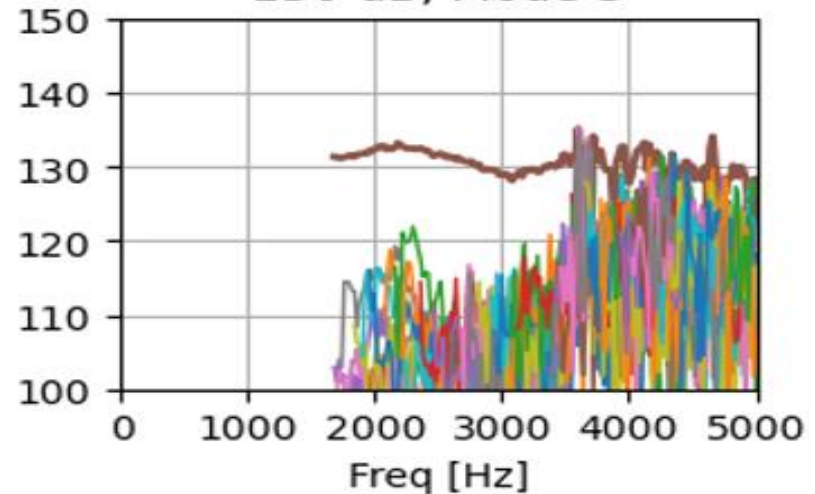


Mode (2,1)

Pseudo Inversion, $M = 0.6$,
130 dB, Mode 0



130 dB, Mode 5



Broadband noise (IL)	Requirement	Measured
Operating conditions	Air flow up to 0.6M	Air flow up to 0.6M
Frequency range	400Hz – 10kHz	400Hz – 10kHz
Modal control	No	No
Acoustic global level	155dB	155dB

Step sine (IL, Transfer matrix, impedance)	Requirement	Measured
Operating conditions	Air flow up to 0.6M	Air flow up to 0.6M
Frequency range	400Hz – 5kHz	400Hz – 5kHz
Modal control	All modes, up to 5kHz	≈ 30 first modes (60 microphones disponibles)
Acoustic level	150dB	150dB



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