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CENTRE DE TRANSFERT
DE TECHNOLOGIE DU MANS

A simplified experimental methodology for exhaust harmonic noise prediction

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Introduction

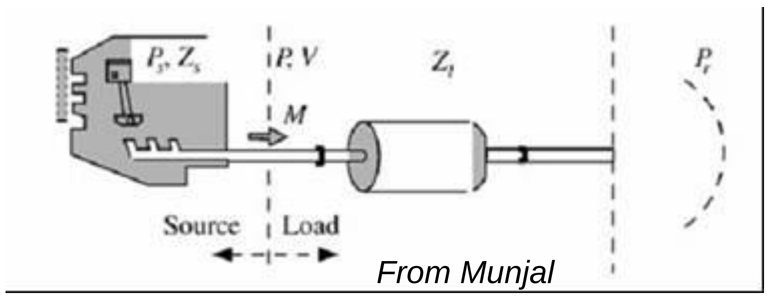
- ✓ Topic: Exhaust harmonic noise prediction for thermal engines
- ✓ Technical perimeter : definition of the exhaust lines
- ✓ Usually done on specific engine test benches
- ✓ Main drawback : in preliminary design phase the engine is not available or only for a short period

- ➢ The aim of this study is to define a experimental method for the design of new exhaust line with a close definition engine
- ➢ Obtain the correct nozzle noise for the target engine
- ➢ At the end of the project when the new engine is available:
  - ✓ Check the new exhaust line definition
  - ✓ Minor corrections if needed

Contents

Concept (i)

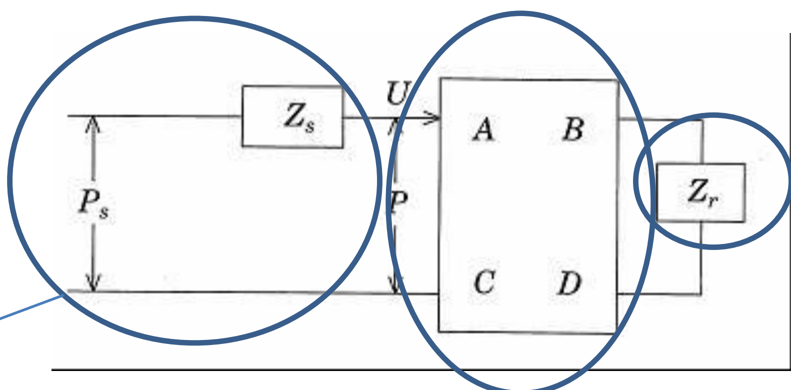
- ✓ Prediction of the exhaust noise :



Engine | Exhaust Line | Exhaust Noise

- ✓ Common use of the classical Thevenin electro-acoustic analogy:

$$P_s = P + Z_s.U$$

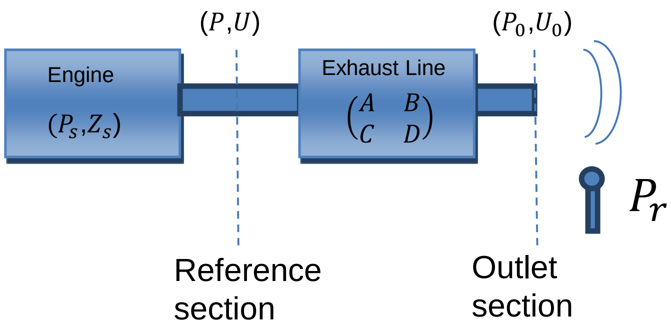


Linked to the exhaust Noise

Engine

Exhaust Line

Concept (ii)



$$P_s = P + Z_s.U$$

- Linearity
- Stationarity

- ✓ P_s & Z_s : source characteristics of the engine
- ✓ P & U : Pressure & acoustic velocity at the inlet of the exhaust line
- ✓ $\begin{pmatrix} A & B \\ C & D \end{pmatrix}$: Transfer matrix of the entire exhaust line
- ✓ Z_r: Radiation impedance linked to the exhaust noise

Concept (iii)

- ✓ The exhaust noise is usually predicted by using monopole radiation model

- ➢ The radiated pressure P_r (function of the frequency ω) at the distance r is directly linked to the acoustic velocity U_0 at the nozzle of the tail pipe (of area A_0) :

$$P_r = f(U_0, A_0, \omega, r) = K.\,U_0$$

- ✓ As f is a linear function, the radiated power is directly proportional to the acoustic velocity U_0 at the nozzle

Concept (iv)

- ✓ Using the classical transfer matrix formalism:

$$U = U_0.(CZ_r + D)$$

- ✓ Using the electro-acoustic analogy:

$$P_s = P + Z_s.U$$

  - ➢ The acoustic velocity at the outlet is:

$$U_0 = \frac{P_s}{(Z_l + Z_s)(CZ_r + D)}$$

$Z_l = \frac{P}{U}$, Impedance of the line at the inlet

- ✓ Finally, the radiated pressure P_r is linked to the source characteristics (P_s, Z_s) in a proportional manner :

$$P_r = \frac{P_s}{(Z_l + Z_s)} \frac{K}{(CZ_r + D)}$$

Main assumptions : linearity + stationarity

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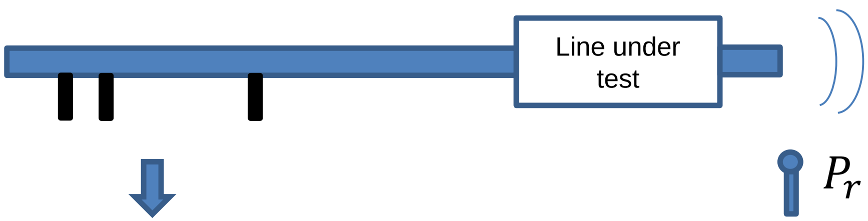
Methodology (i)

1st step: Measurement of the transfer of the line



P_{ac}, Q_{ac}

$$P_s' = P_{ac} + Z_s' Q_{ac} \qquad Z_l = \frac{P_{ac}}{Q_{ac}}$$

P_s', Z_s': source characteristics of the bench (acoustical sources, junctions…)

Z_s' : should be measured before

Z_l : inlet impedance of the line

$$\text{From } P_r = \frac{P_s}{(Z_l + Z_s)} \frac{K}{(CZ_r + D)}$$

$$T_{line} = \frac{K}{(CZ_r + D)}$$

$$= \frac{P_r}{P_s' / (Z_s' + Z_l)}$$

T_{line} and Z_l depends on the operating conditions (flow, temperature and acoustic pressure level)

Methodology (ii)

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2nd step: prediction of the radiated sound at the nozzle with engine source

$$P_r^{Engine} = T_{line} \cdot \frac{P_s}{(Z_s + Z_l)}$$

(P_s, Z_s) : source characteristics of the engine

Z_l : inlet impedance of the line (measured during the previous step, supposed to be invariant)

Contents

Experimental validation (i)

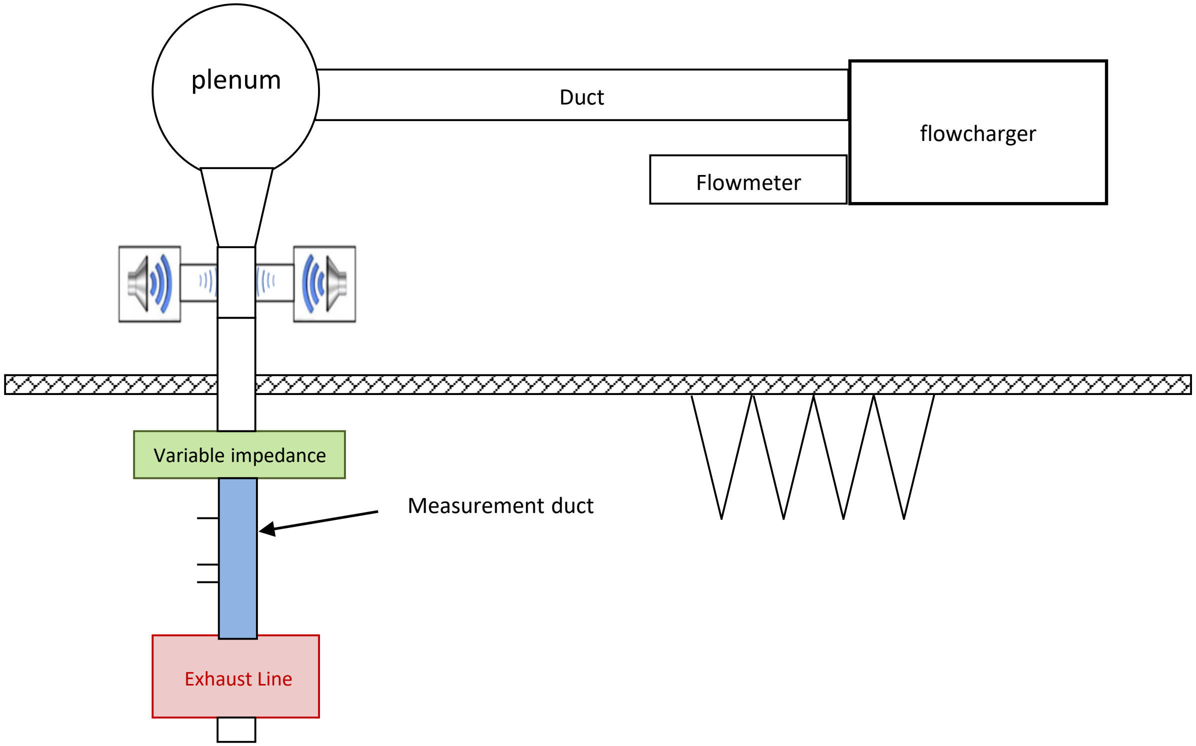
➢ Put into practice the methodology on a standard bench with flow

Bench characteristics :

Steady flow,

Ambient temperature

Frequency variation to simulate **H2** and **H4** of four strokes engine



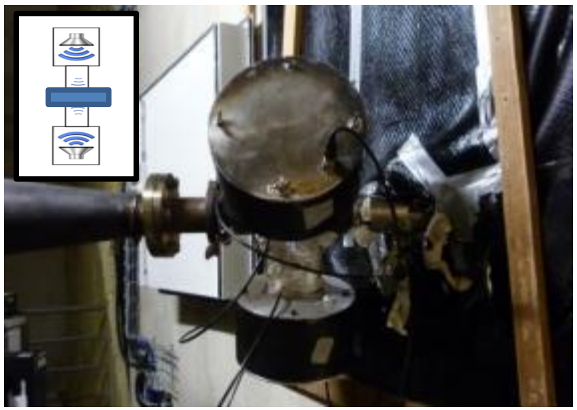
➢ 4 « Synthetic Engines », acoustical sources in series with several passive devices

➢ 4 different (P_s, Z_s)

Experimental validation (ii)

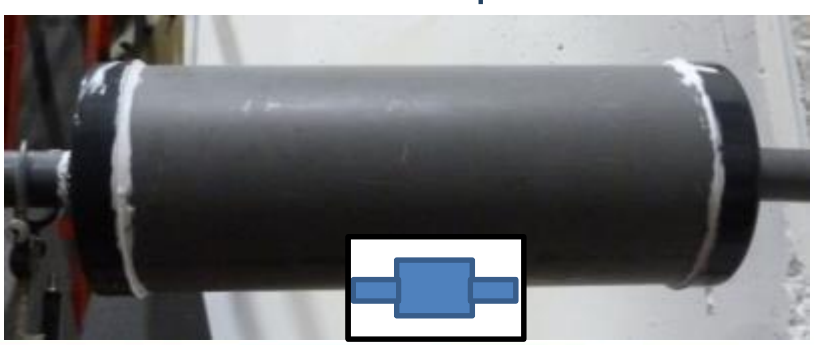
4 synthetic engines

Source 1 :
Acoustical sources



Source 2 :
Acoustical sources + anéchoïc termination

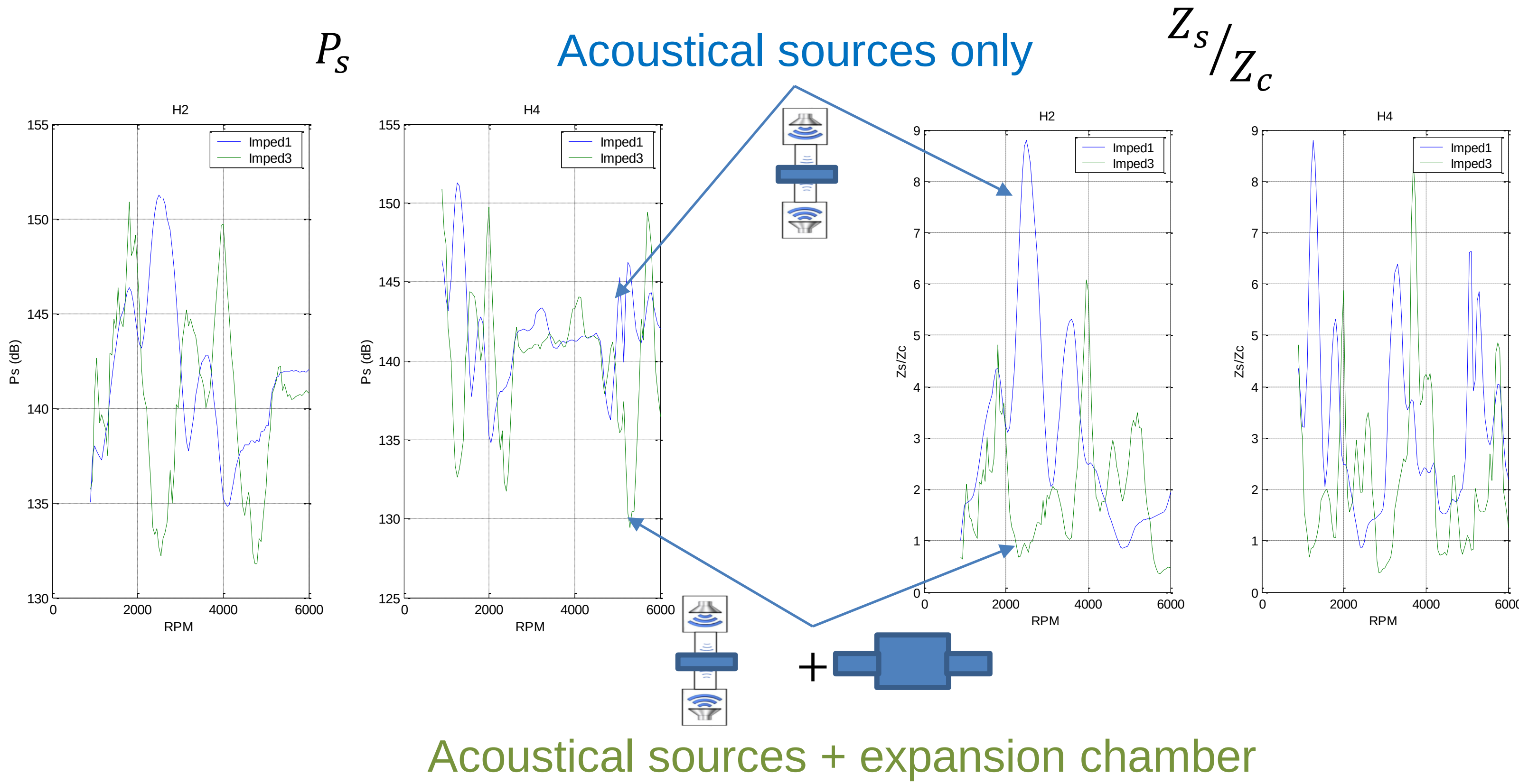
Source 3 :
Acoustical sources + expansion chamber



Source 4 :
Acoustical sources + Catalytic converter

Experimental validation (iii)

Exemple of (P_s, Z_s) at 200 kg/h and 140 dB

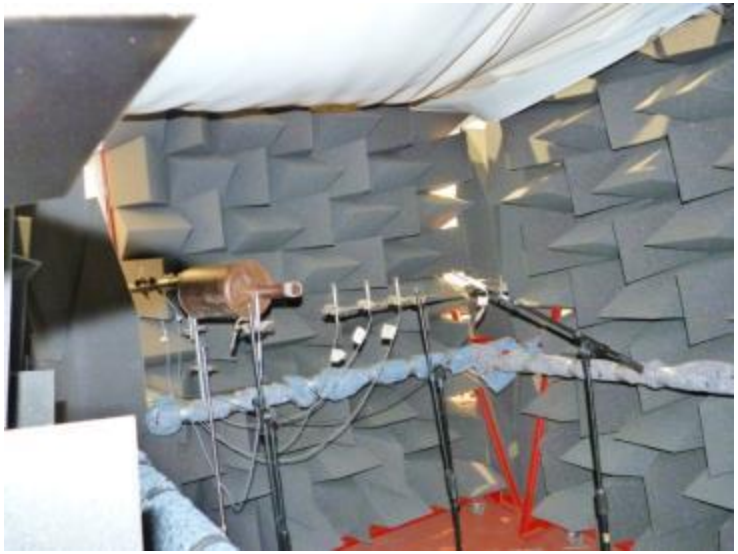


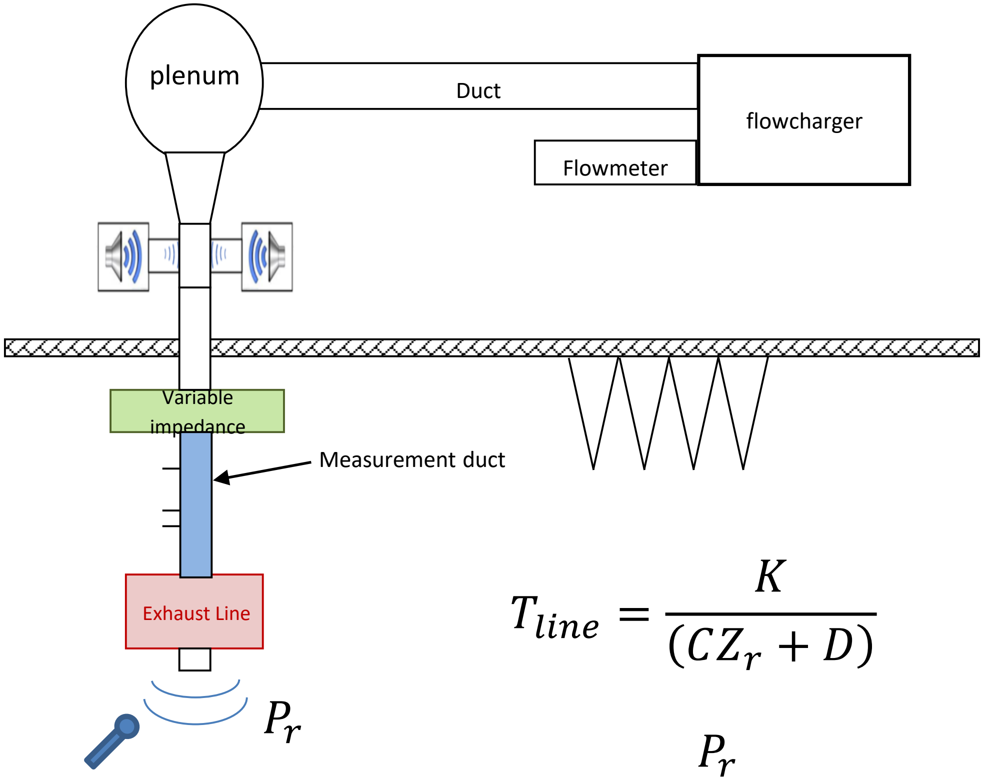
➢ (P_s, Z_s) well different between them

Experimental validation (iv)

Measurement of the transfer of the line

- 1 muffler
- For each sources





$$T_{line} = \frac{K}{(CZ_r + D)}$$

$$= \frac{P_r}{P'_s / (Z'_s + Z_l)}$$

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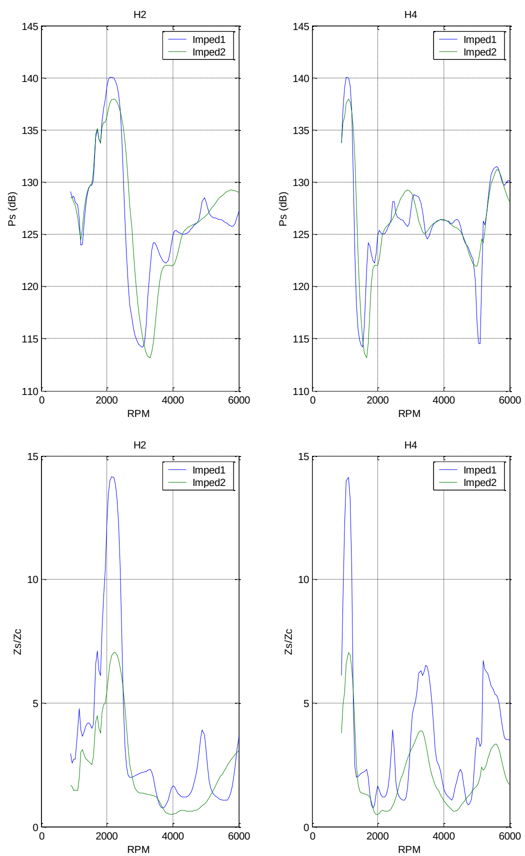
1. Theoretical concepts
2. Methodology description
3. Experimental set-up
4. Results
5. Conclusion & Outlook

Results (i)

Qm =0 kg/h

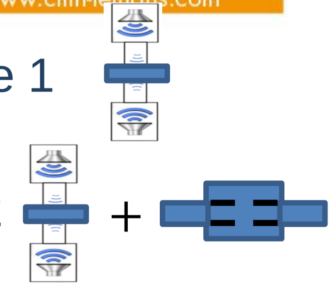
Ps

Zs

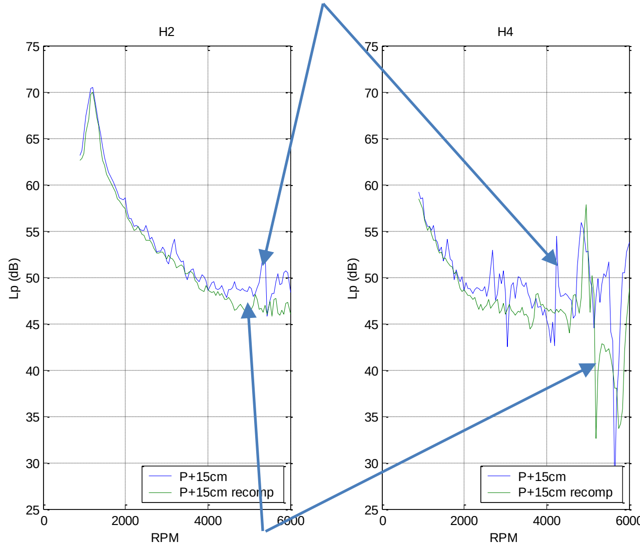


Transfer line with Source 1

Prediction with Source 2 +



Measures



Calculation

➢ Good prediction for H2, satisfactory for H4

Results (ii)

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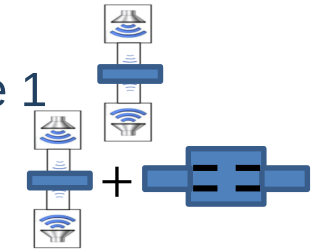
Qm =200 kg/h – 140 dB

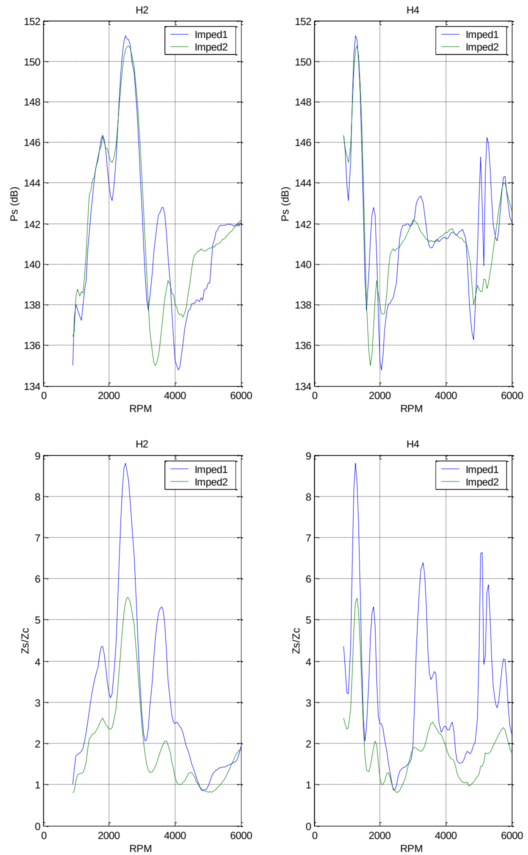
Transfer line with Source 1

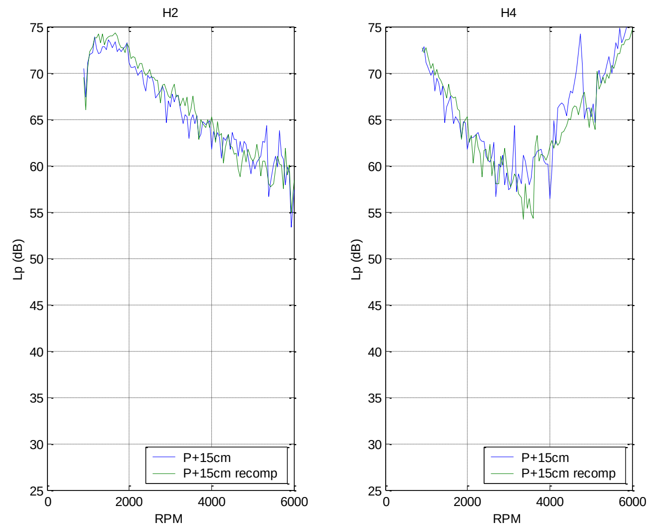
Prediction with Source 2



Ps

Zs





Prediction

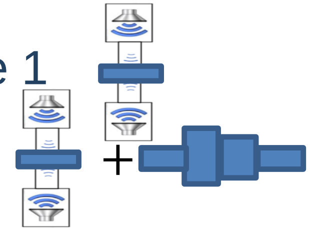
- Still work with flow

Results (iii)

Qm =200 kg/h – 140 dB

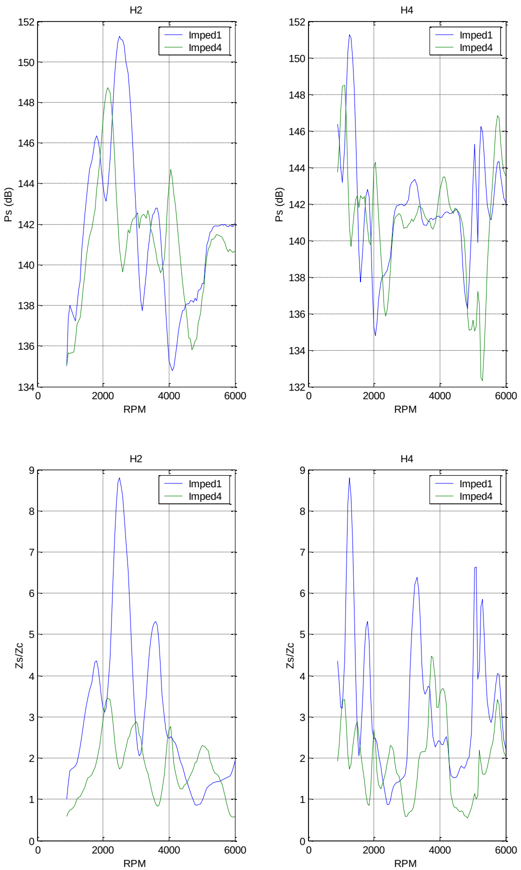
Transfer line with Source 1

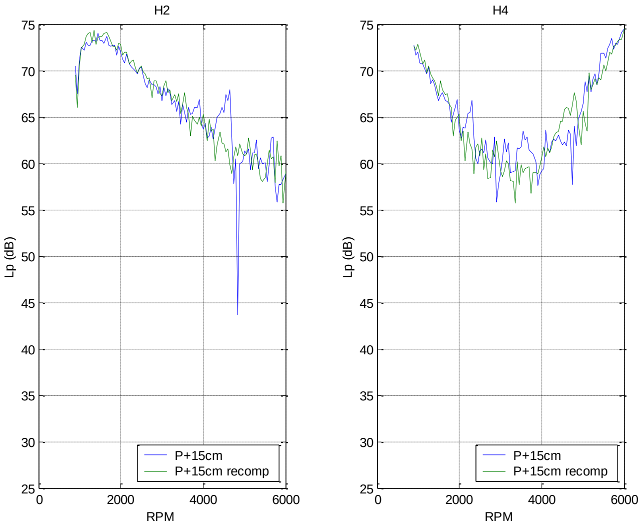
Prediction with Source 4



Ps

Zs





Prediction

- ➢ Still work with other source

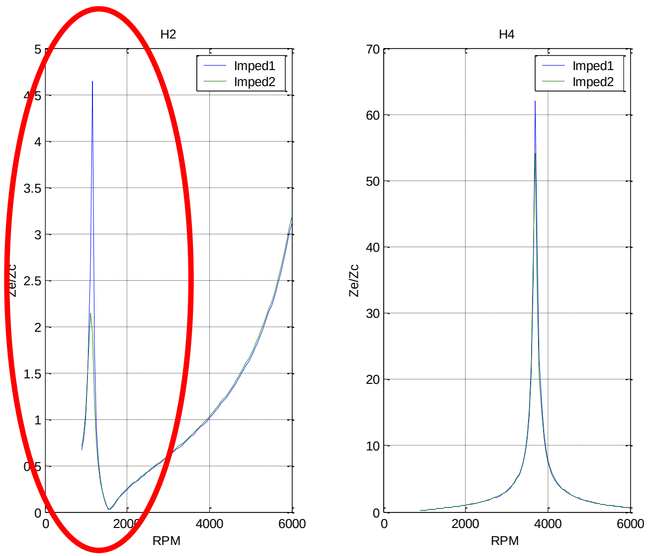
Results (iv)

Exercice 1: Transfer : Source 1 – Q=0kg/h (like run-down) – **Low pressure level**

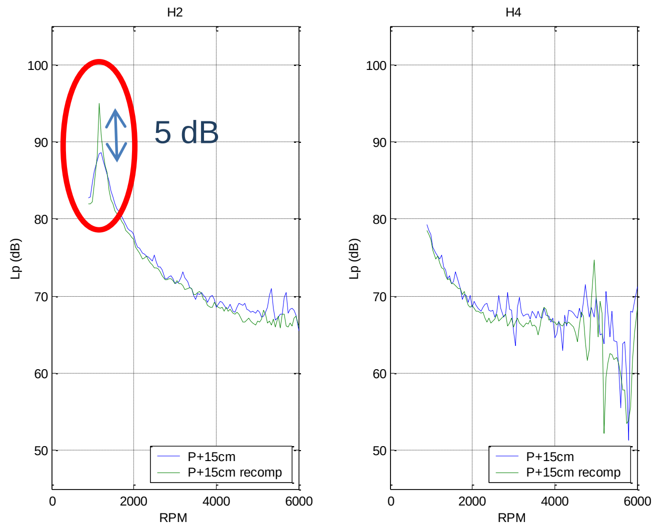
Prediction : Source 2 - Q=0kg/h – **High pressure level**

(i.e : we don't choose the correct transfer function)

Z_l



Prediction



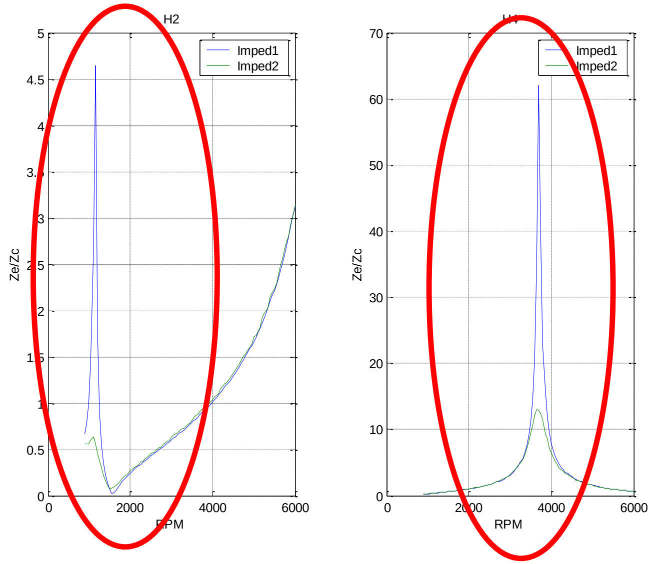
➢ We find a well-known effect : the effect of pressure level on resonances

Results (v)

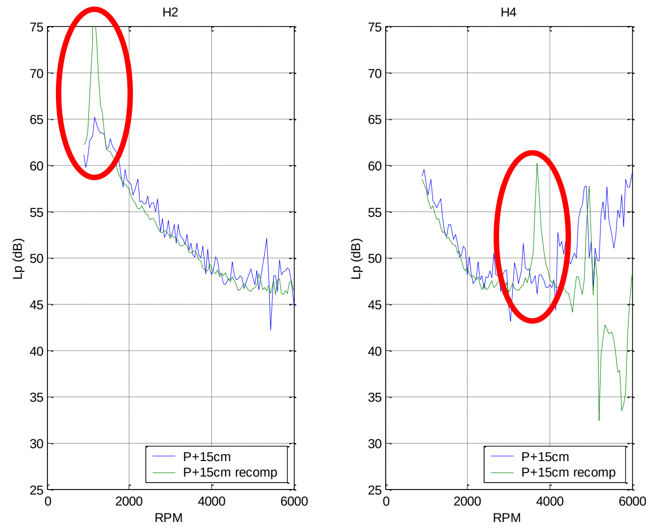
Exercice 2: Transfer : Source 1 – Q=0kg/h

Prediction : Source 2 - **Q=100kg/h**

Z_l



Prediction



➢ We find a well-known effect : the effect of flow rate on resonances

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Conclusion

- ✓ Methodology validated with lab bench : robust prediction
- ✓ We can reproduce the effects of flow and acoustic pressure level
- ✓ Caution : have representative acoustic sources for engine
  - ➢ 2nd order with flow : just use the correct flow (and temperature)
  - ➢ In run-down (no-flow) : a strong acoustic source is mandatory

Outlook

- ✓ Validate the methodology with :
  - ➢ Real engines
  - ➢ Various exhaust lines with different types of muffler