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Overview of James B. Moreland's 1976 paper on: Controlling Industrial Noise by Means of Room Boundary Absorption

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CLASSIC PAPERS IN NOISE CONTROL

Overview of James B. Moreland's 1976 paper on: Controlling Industrial Noise by Means of Room Boundary Absorption

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1. INTRODUCTION TO THE BACKGROUND

1.1 About the author[1]

James B. Moreland (August 22nd 1938 – Aug 22nd 2004) was an **Engineer / Executive at Westinghouse Research Center in Churchill, PA from 1967 to 1994 and later became the President of Jaymore Electrical Products and Systems**. He engaged in acoustics research for more than 40 years. While serving at Westinghouse, Mr. Moreland **conducted studies and trainings in a number of areas of applied acoustics**. The results of these studies included the **development and testing of analytical methods to predict the noise radiation from fans, and the benefit from various noise control measures such as absorption surfaces, barriers, and partial enclosures to be used in factories and offices.** The activities led by him provided analysis and design technology related to the production, transmission and reception of sound in order to **allow Westinghouse products to meet standards, minimize annoyance and avoid unwanted defections**. Through development and application of specialized measurement techniques, his group provided diagnosis leading to noise detection and control of abnormally functioning equipment. Mr. Moreland was a member of the Acoustical Society of America, the Working Group on Sound Level Requirements in the IEEE Power Circuit Breaker Subcommittee, and the ANSI Working Group, SI-67, on developing methods for the measurement and analysis of impulsive noise. He published over 60 technical articles and reports, including the chapter "Electrical Equipment Noise" in the revised Handbook of Noise Control by Cyril Harris.

James B. Moreland[1]

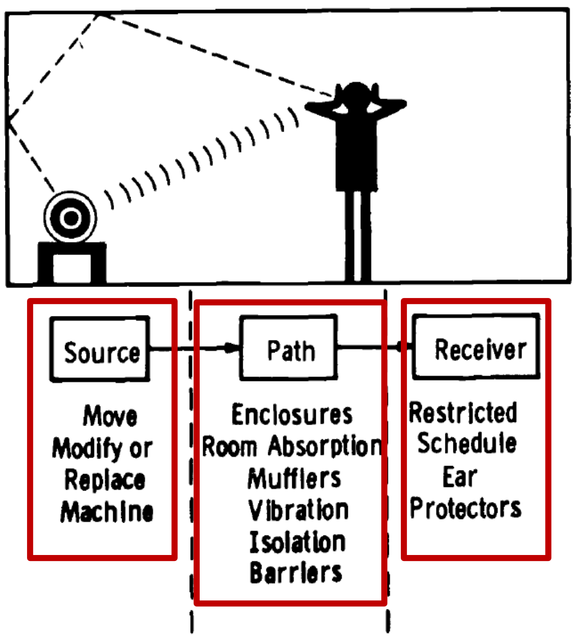
1. INTRODUCTION TO THE BACKGROUND

1.2 Industrial / Occupational noise control[2,3]

- Loud industrial noise exposure may cause temporary / permanent threshold shift (hearing loss) depending on the exposure duration.
- Based on the Occupational Safety and Health Administration (OSHA) noise regulation:

Duration per day, hours	Sound level dBA slow response
8	90
6	92
4	95
3	97
2	100
1 1/2	102
1	105
1/2	110
1/4 or less	115

Permissible noise exposure durations[2]

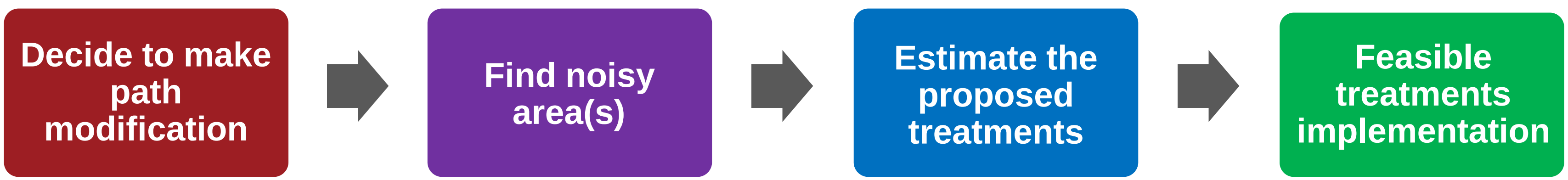


System approach to noise control[3]

1. INTRODUCTION TO THE BACKGROUND

1.3 Motivations of the study in the classic paper

- **To meet the OSHA noise exposure requirement and to provide protection against work-related hearing loss in an 8 working hours standard:**



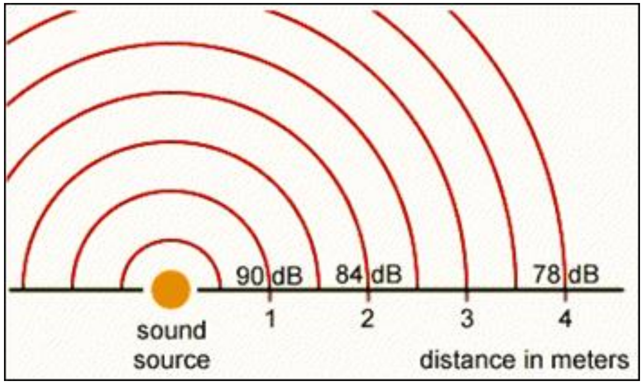
  - First of all, **path modification** was recommended by OSHA to be the most appropriate solution for most industrial noise control problems.
  - To outline the problem, a **noise assessment method** was required to identify areas in the industrial plant which exceed 90dB(A)[4] noise level limit.
  - Then, accurate **noise control performance predictions** of these treatments were necessary before the implementations.
  - Based on the prediction, the feasible engineering **noise control treatments** could to be implemented to the identified areas.

2. REVIEW OF THE CLASSIC PAPER: METHODS AND CONCLUSIONS

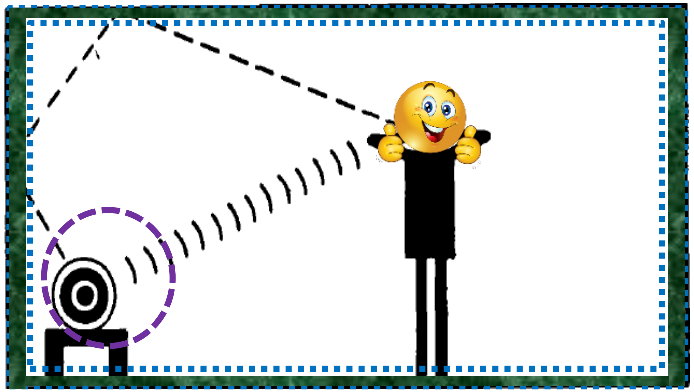
2.1 Sound propagation in rooms

- **Sound propagation in free space (no reflection): Inverse Square Law (ISL)**
  - **ISL**: Sound Pressure Level (SPL) generally decreases 6dB per doubling of distance.

- **Sound propagation in a room (sound source + reflection): More complicated**
  - **Near the source (direct-field)**: sound energy of the source predominates
  - **Away from the source (reverberant field)**: reflected/reverberant sound energy predominates



Sound propagation in free space[5]



Sound propagation in an enclosed room[3]

Absorptive room boundaries to modify the path at the reverberant field

- **Absorptive room boundaries treatment estimation: evaluate their noise-reducing effectiveness.**

2. REVIEW OF THE CLASSIC PAPER: METHODS AND CONCLUSIONS

2.1 Sound propagation in rooms

- **Evaluation of noise-reducing effectiveness: Insertion Loss* (IL)[3,6]**

$$\mathrm{IL}(r) = \mathrm{SPL}_2 - \mathrm{SPL}_1 \qquad (1)$$

  - SPL_2: sound pressure level **after** adding absorptive room boundaries, [dB] re. 2×10^{-5} N/m^2.
  - SPL_1: sound pressure level **before** adding absorptive room boundaries, [dB] re. 2×10^{-5} N/m^2.

- By direct measurement or by **Sabine Approach[3,7] (following slides)**.

$$\mathrm{SPL}(r) = \mathrm{PWL} + 10\log_{10}\left(\frac{Q}{4\pi r^2} + \frac{4}{A}\right) \qquad (2)$$

  - PWL: measured sound power level at the source, [dB] re. 10^{-12} W.
  - r: measured distance from source to the receiver, [m].
  - Q: directivity factor.[8]
    - **Refer the table.**
  - A: total room absorption, [m^2].
  - **Evaluated by methods on following slide.**

Situation	Directivity factor, Q
free space	1
centred in a large flat surface	2
centred at the edge formed by the junction of two large flat surfaces	4
at the corner formed by the junction of three large flat surfaces	8

*IL: in this study, IL's were all negative because of the sound attenuation.

2. REVIEW OF THE CLASSIC PAPER: METHODS AND CONCLUSIONS

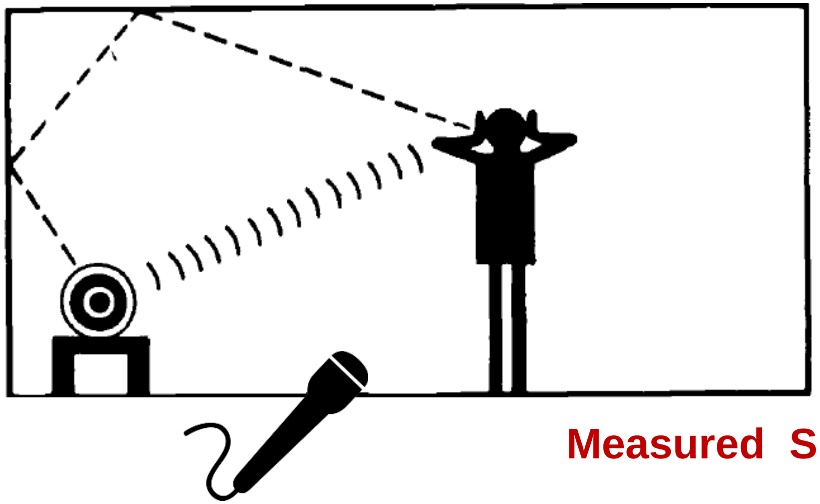
2.1 Sound propagation in rooms

- **Determination of room absorption, *A***
  - Reverberation time method (72℉ or 22℃ room temperature): $A = \frac{0.161V}{T}$ (3)
    - T: reverberation time
    - V: room volume
  - Absorption coefficient method: $A = \sum S_i \alpha_i + 4mV$ (4)
    - α_i: absorption coefficients room boundary i.
    - S_i: area of room boundary i.
    - m: energy absorption constant of air,[7,9] [Np/m]
    - V: room volume
  - SPL method: $A = 10^{(\mathrm{PWL}-\mathrm{SPL}+16)/10}$ (5)
    - SPL: reverberant field sound pressure level at steady state* , [dB] re. 2×10^{-5} N/m^2
    - PWL: source sound power level, [dB] re. 10^{-12} W.

2. REVIEW OF THE CLASSIC PAPER: METHODS AND CONCLUSIONS

2.2 Absorptive room boundaries -- Acoustical sprays

- **Testing room**: with a 20914m^2 total surface area and a 9.2m ceiling height.



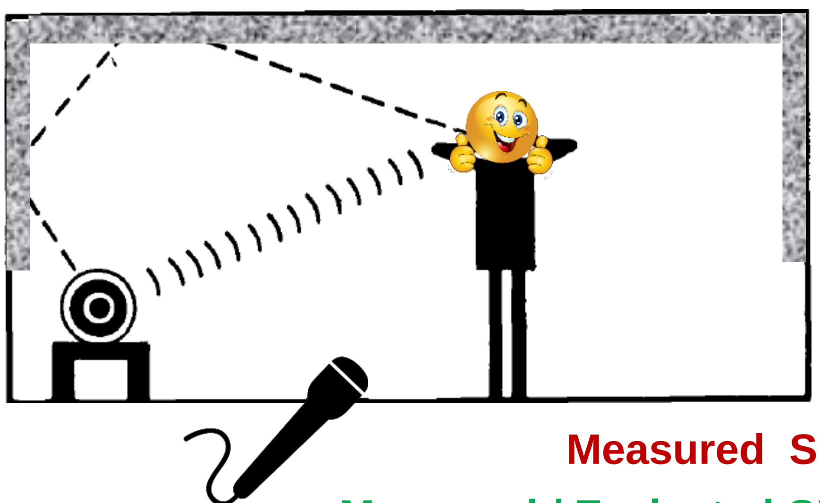
Measured SPL_1

"Popcorn ceiling" with acoustical spray[10]

2. REVIEW OF THE CLASSIC PAPER: METHODS AND CONCLUSIONS

2.2 Absorptive room boundaries -- Acoustical sprays

- **Testing room**: with a 20914m^2 total surface area and a 9.2m ceiling height.
- **Treatment**: the ceiling and upper 2/3 walls was covered with acoustical spray-on material.



"Popcorn ceiling" with acoustical spray[10]

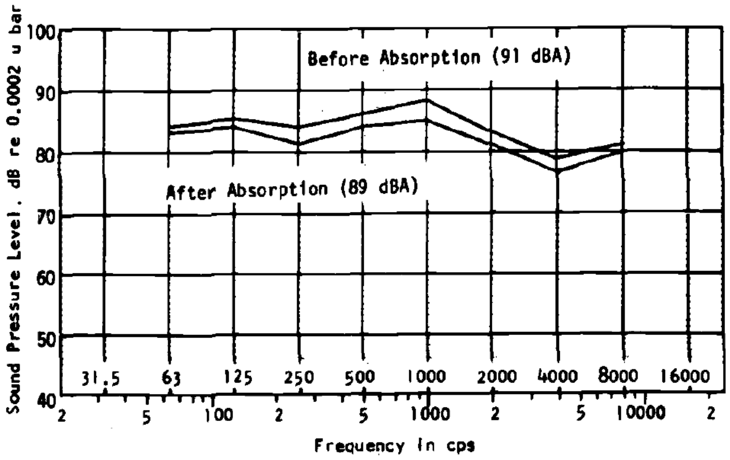
Measured SPL$_1$
Measured / Evaluated SPL$_2$
} **IL by Eq. (1)**

2. REVIEW OF THE CLASSIC PAPER: METHODS AND CONCLUSIONS

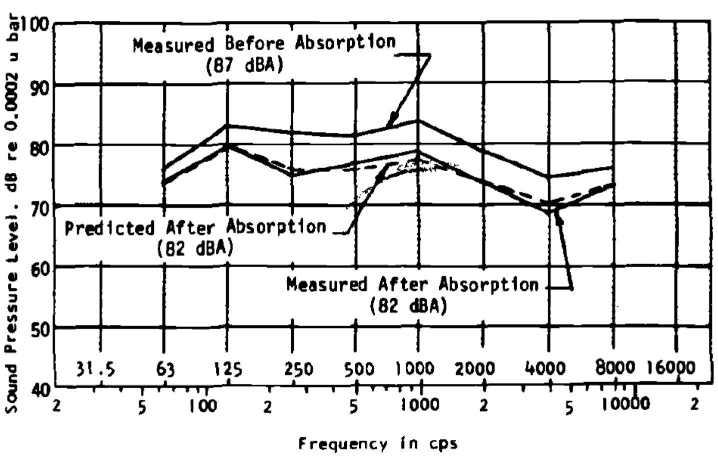
2.2 Absorptive room boundaries -- Acoustical sprays

- **Testing room**: with a 20914m^2 total surface area and a 9.2m ceiling height.
- **Treatment**: the ceiling and upper 2/3 walls was covered with acoustical spray-on material.
- **Findings**: attenuation increases with increasing distance (**due to noise-reduction at the reverberant field**).

  Eq. (1) IL evaluations was validated by SPL measurements.



3m from the sound source –
SPL spectrum before and after adding acoustical spray[3]

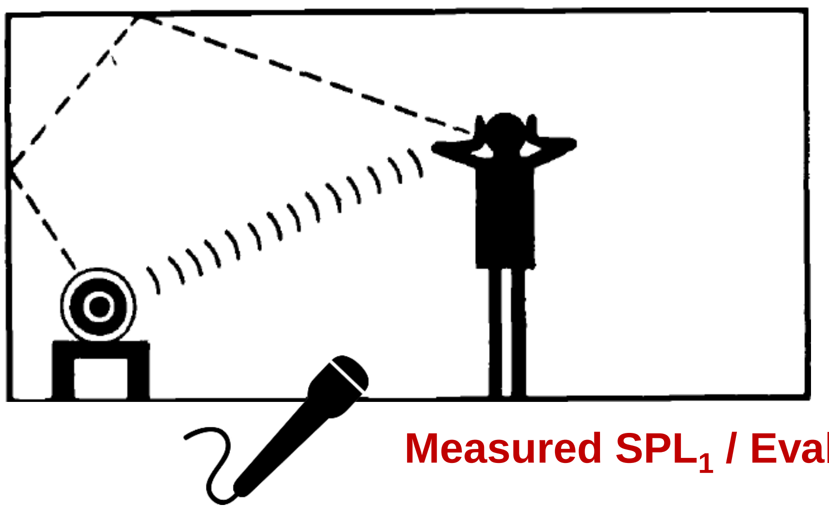


15m from the sound source –
SPL spectrum before and after adding acoustical spray[3]

2. REVIEW OF THE CLASSIC PAPER: METHODS AND CONCLUSIONS

2.2 Absorptive room boundaries -- Suspended absorbers

- **Testing room**: high bay area (14.6m ceiling height) with openings leading to other plant areas.



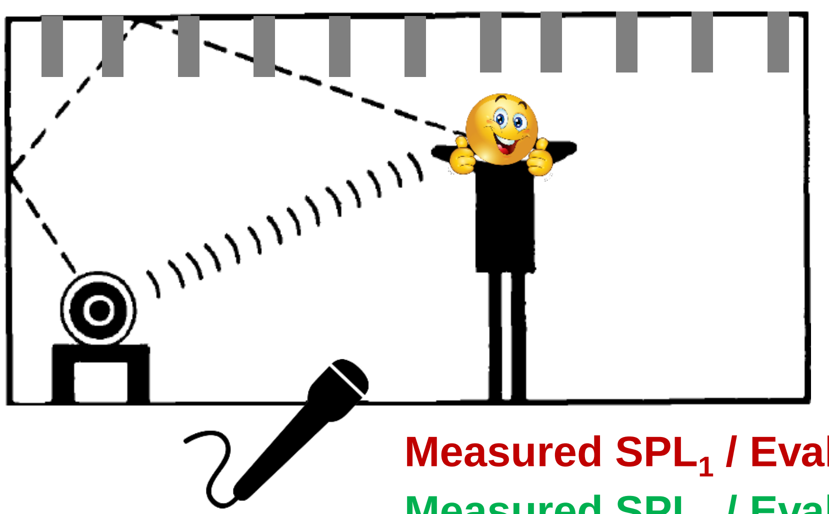
Suspending sound absorbing units[11]

Measured SPL_1 / Evaluated SPL_1 by Eq.(2)

2. REVIEW OF THE CLASSIC PAPER: METHODS AND CONCLUSIONS

2.2 Absorptive room boundaries -- Suspended absorbers

- **Testing room**: high bay area (14.6m ceiling height) with openings leading to other plant areas.
- **Treatment**: fibrous sound absorbing units hanging from the ceiling.



Suspending sound absorbing units[11]

Measured SPL_1 / Evaluated SPL_1 by Eq.(2)

Measured SPL_2 / Evaluated SPL_2 by Eq.(2)

2. REVIEW OF THE CLASSIC PAPER: METHODS AND CONCLUSIONS

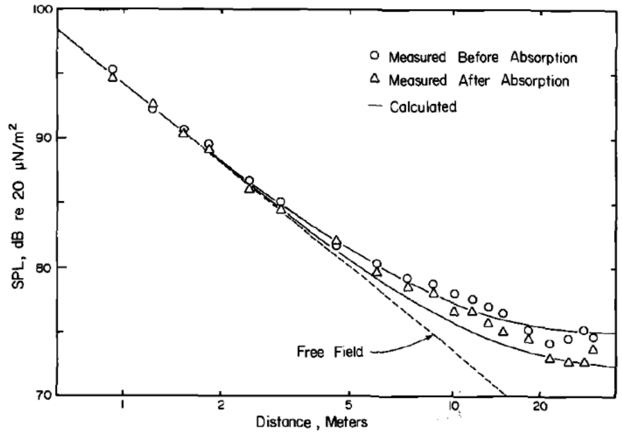
2.2 Absorptive room boundaries -- Suspended absorbers

- **Testing room**: high bay area (14.6m ceiling height) with openings leading to other plant areas.
- **Treatment**: fibrous sound absorbing units hanging from the ceiling.
- **Findings**: attenuation increases with increasing distance (**due to noise-reduction at the reverberant field**).

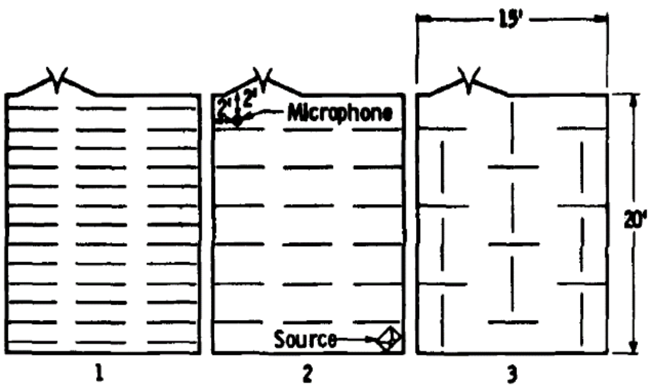
  increasing panels spacing may help with sound absorption per panel.

  different configurations provided no increase in IL.

  evaluated data could be used as raw estimation when measured data was fluctuating.



SPL before and after adding suspended absorbers *vs.* distance from source at 1000Hz octave band[3,12]



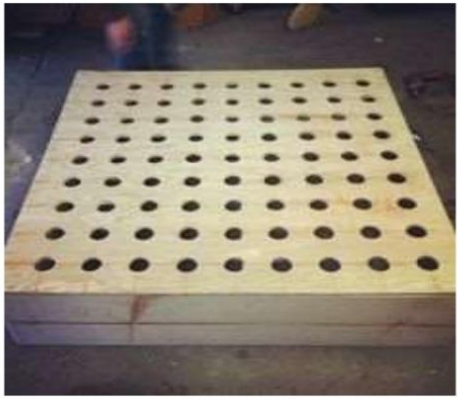
Different suspended panel conigurations[3]

2. REVIEW OF THE CLASSIC PAPER: METHODS AND CONCLUSIONS

2.2 Absorptive room boundaries -- Resonators

- **Treatment**: 0.64cm thick plexiglass sheet with fourteen 0.32cm-diameter holes uniformly spaced 2.54cm apart, individual cavities with depth 2.1cm, combined with extra fibrous layer and perforated metal screen

- **No measurement conducted for this case.**
- **Evaluated SPL_1, SPL_2 and IL's by Eqs. (1) and (2) based on published room absorption data.**



Helmholtz resonators[13]

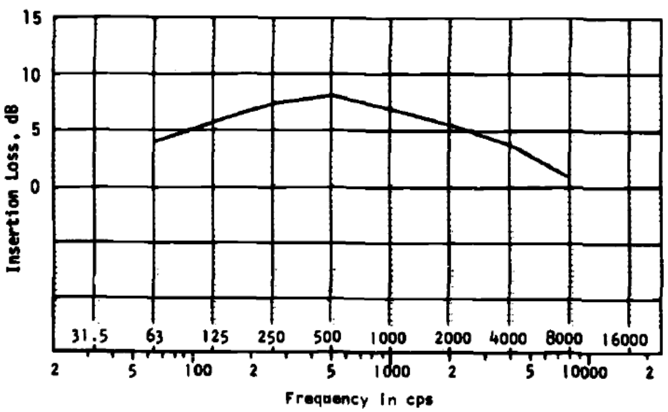
2. REVIEW OF THE CLASSIC PAPER: METHODS AND CONCLUSIONS

2.2 Absorptive room boundaries -- Resonators

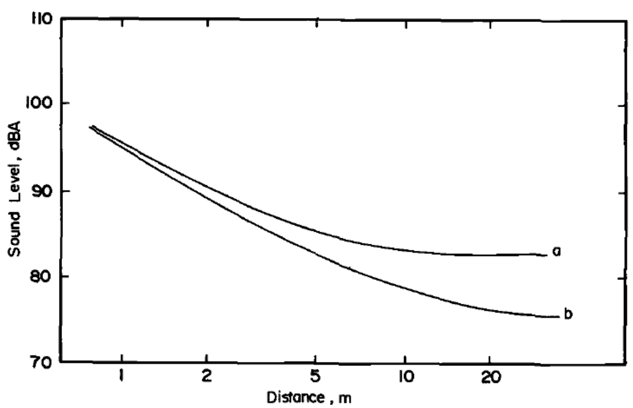
- **Treatment**: 0.64cm thick plexiglass sheet with fourteen 0.32cm-diameter holes uniformly spaced 2.54cm apart, individual cavities with depth 2.1cm, combined with extra fibrous layer and perforated metal screen
- **Findings**: attenuation increases with increasing distance (**due to noise-reduction at the reverberant field**).

  this Helmholtz resonators' effective sound absorption is around 500 Hz.

  evaluation data could be used as raw estimation when measurements were not applicable.



IL's spectrum for the resonators[3]



SPL before and after adding resonators *vs.* distance from source at 500Hz octave band[3,12]

2. REVIEW OF THE CLASSIC PAPER: METHODS AND CONCLUSIONS

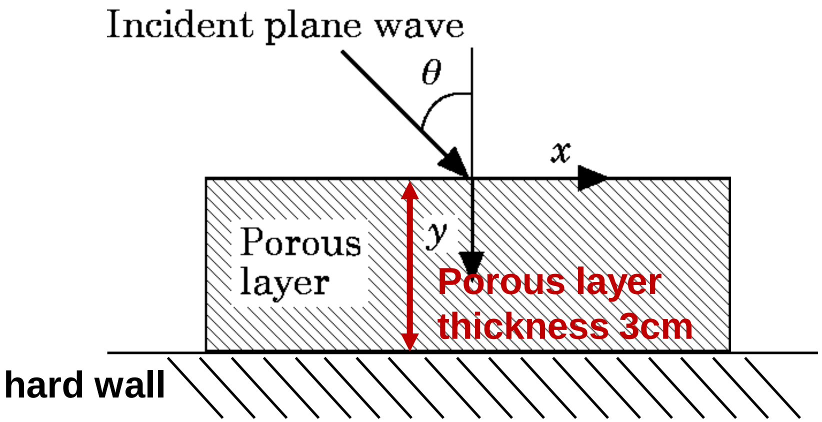
2.3 Conclusions

- To finding appropriate solution for industrial noise problem, **accurate estimation of the engineering noise control performance (noise-reducing effectiveness by IL) is necessary**.
- The noise-reducing performance of different absorptive room boundaries could be estimated either by **model-evaluated SPL or direct measured SPL**.
- If the estimation was based on SPL / IL evaluation, **room absorption *A* also needs to be pre-determined accurately**.
- Broadband absorptive room boundaries such as acoustical spray-on material or suspended absorbers are often used for plants, while narrowband absorptive room boundaries such as Helmholtz resonators are often used for new industrial facilities. However, applications of these room boundaries may need to be in conjunction with other acoustical elements such as barriers, porous layers and perforated panels to be quite cost-effective.

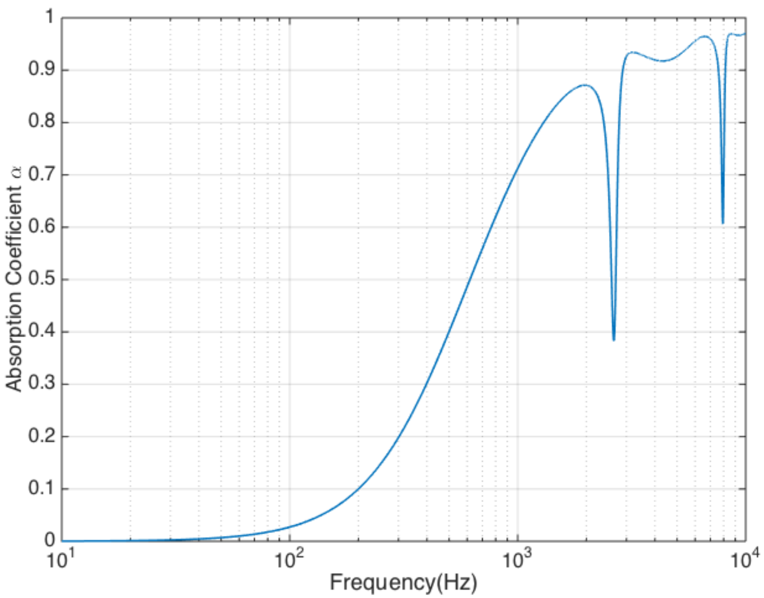
3. DISCUSSION AND INDICATIONS

3.1 Model for absorption coefficient prediction

- State-of-the-art model[14] provides accurate prediction of absorption coefficient, α, which helps with accurately evaluating ***A***, **SPL** and **IL** in perfectly diffuse field.



Physical configuration[14]



Normal incidence Absorption coefficient, α, for a 3cm single layer poro-elastic fibrous material attached to a hard wall

REFERENCES

1. Moreland J B. "Low Frequency Noise Reduction of Acoustic Enclosures." *Noise Control Engineering Journal*; November-December 1984; Vol. 23, No. 3, p. 140-149.

2. United States Department of Labor. "Occupational noise exposure." *Occupational Safety and Health Standards*; 1910.95(b)(2); https://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=standards&p_id=9735

3. Moreland J B. "Controlling Industrial Noise by Means of Room Boundary Absorption." *Noise Control Engineering Journal*; November-December 1976; Vol. 7, No. 3, p. 149-153.

4. https://en.wikipedia.org/wiki/A-weighting

5. https://www.osha.gov/dts/osta/otm/new_noise/

6. https://en.wikipedia.org/wiki/Insertion_loss

7. Vér I L, Beranek L L. "Noise and Vibration Control Engineering: Principles and Applications". *John Wiley & Sons, Inc.* 2nd edition; p. 185

8. Hansen C H, Sehrndt CH. "Fundamentals of acoustics". *Occupational Exposure to Noise: Evaluation, Prevention and Control. World Health Organization.* Chap. 1, p. 38-39

9. https://en.wikipedia.org/wiki/Attenuation

10. https://en.wikipedia.org/wiki/Popcorn_ceiling

11. https://www.buildingdesignindex.co.uk/entry/35740/Soundsorba/BAFFLESORBA-suspended-noise-absorbers/

12. https://en.wikipedia.org/wiki/Octave_band

13. https://www.slideshare.net/gpkpankaj/room-acoustics-and-sound-absorption-materials

14. Bolton J S, Shiau N-M, and Kang Y J. "Sound Transmission Through Multi-panel Structures Lined with Elastic Porous Materials". *Journal of Sound and Vibration*; 1996; 191(3), p. 317-347.

Thank You!