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Using Simulation to Determine Attenuation of HVAC Ductwork

David Herrin
University of Kentucky

Overview

- Unlined and Lined Duct Insertion Loss
- Elbow Insertion Loss
- Plenum Insertion Loss
- Duct Breakout Noise

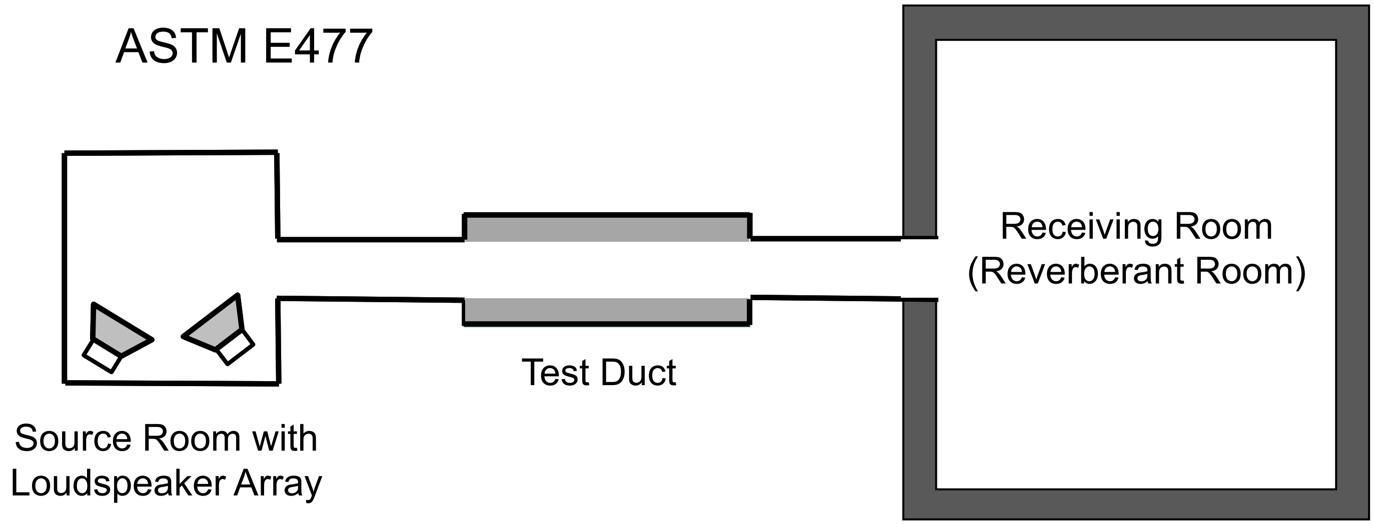
Prior ASHRAE Sponsored Work

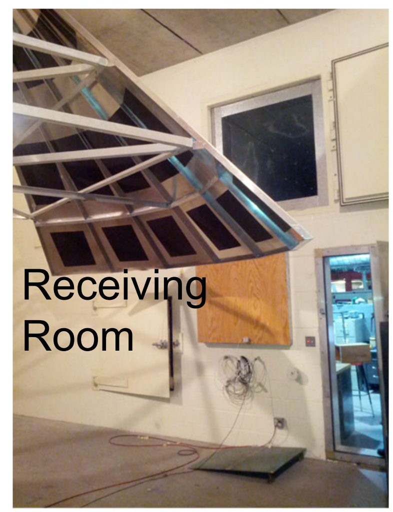
- Vér, I.L. 1978. A review of the attenuation of sound in straight lined and unlined ductwork of rectangular cross section. *ASHRAE Transactions* 84(1):122-149.
- Kuntz, H.L. and R.M Hoover. 1987. The interrelationships between the physical properties of fibrous duct lining materials and lined duct sound attenuation. *ASHRAE Transactions* 93(2):449-470.
- Reynolds, D.D. Reynolds, D.D. and J.M. Bledsoe. 1989a. Sound attenuation of unlined and acoustically lined rectangular ducts. *ASHRAE Transactions* 95(1):90-95.
- J.M. Bledsoe. 1989b. Sound attenuation of acoustically lined circular ducts and radiused elbows. *ASHRAE Transactions* 95(1):96-99.

Limitation Measurement-based studies based on a limited number of duct cross-sectional areas and lining lengths.

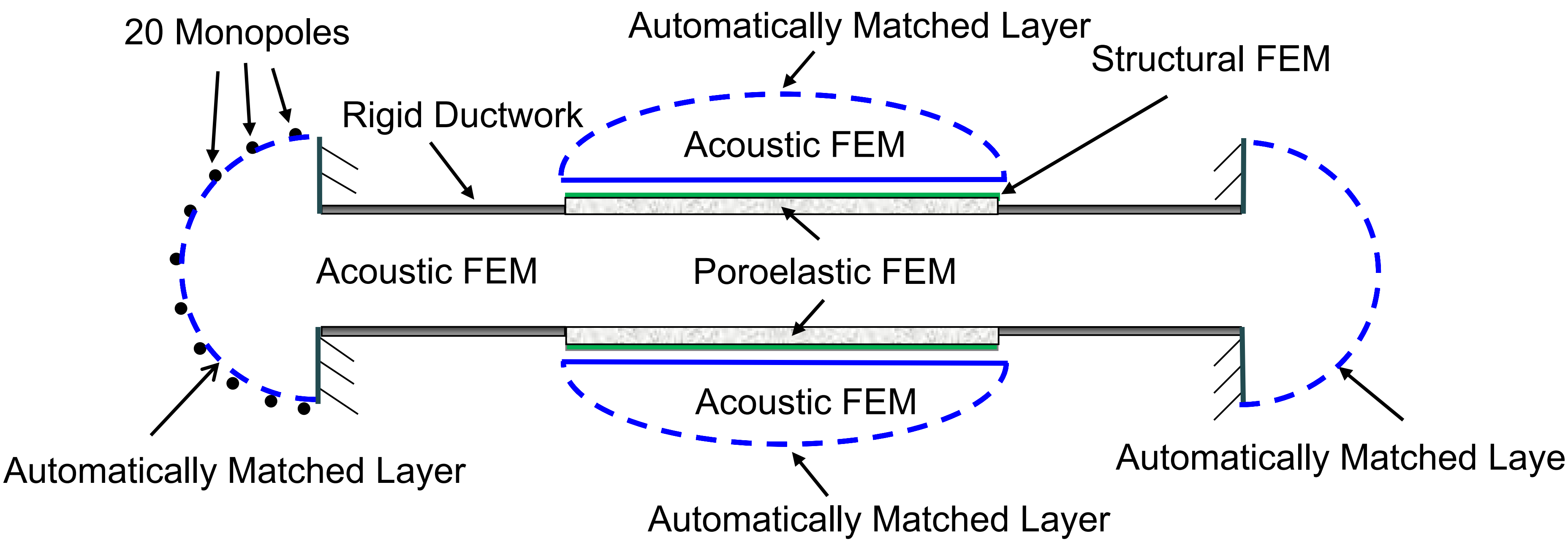
RP-1408 Campaign

ASTM E477

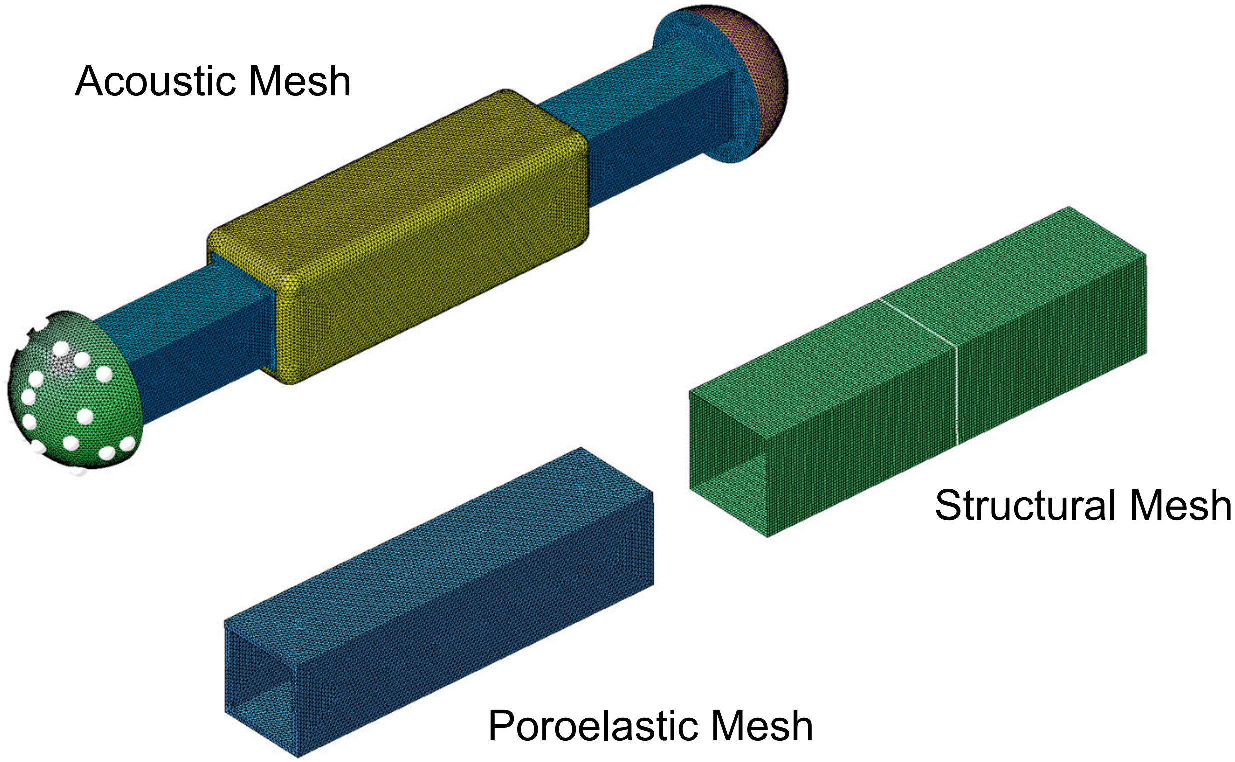




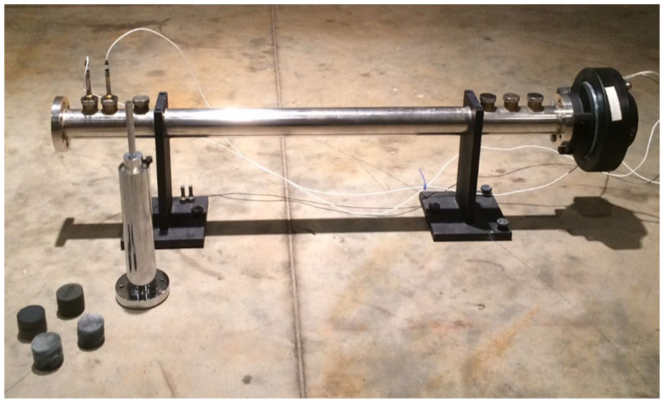
Modeling Approach

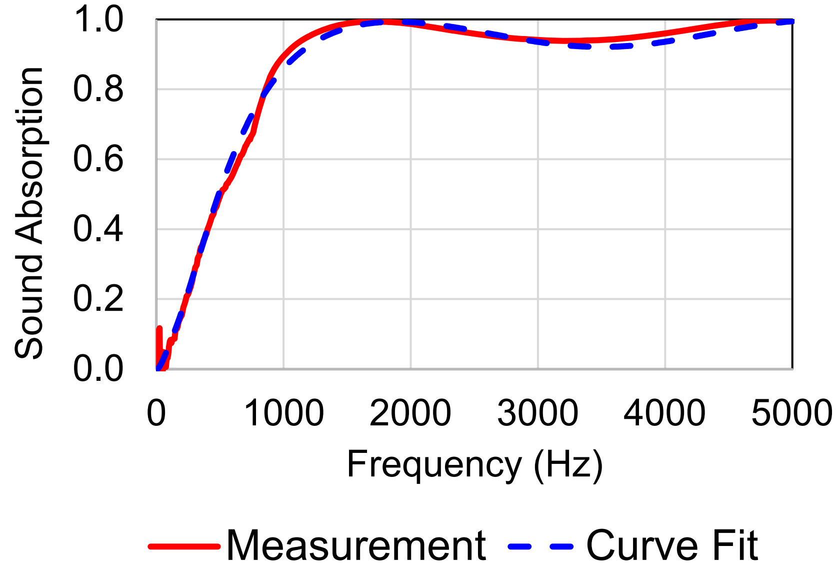


Modeling Approach



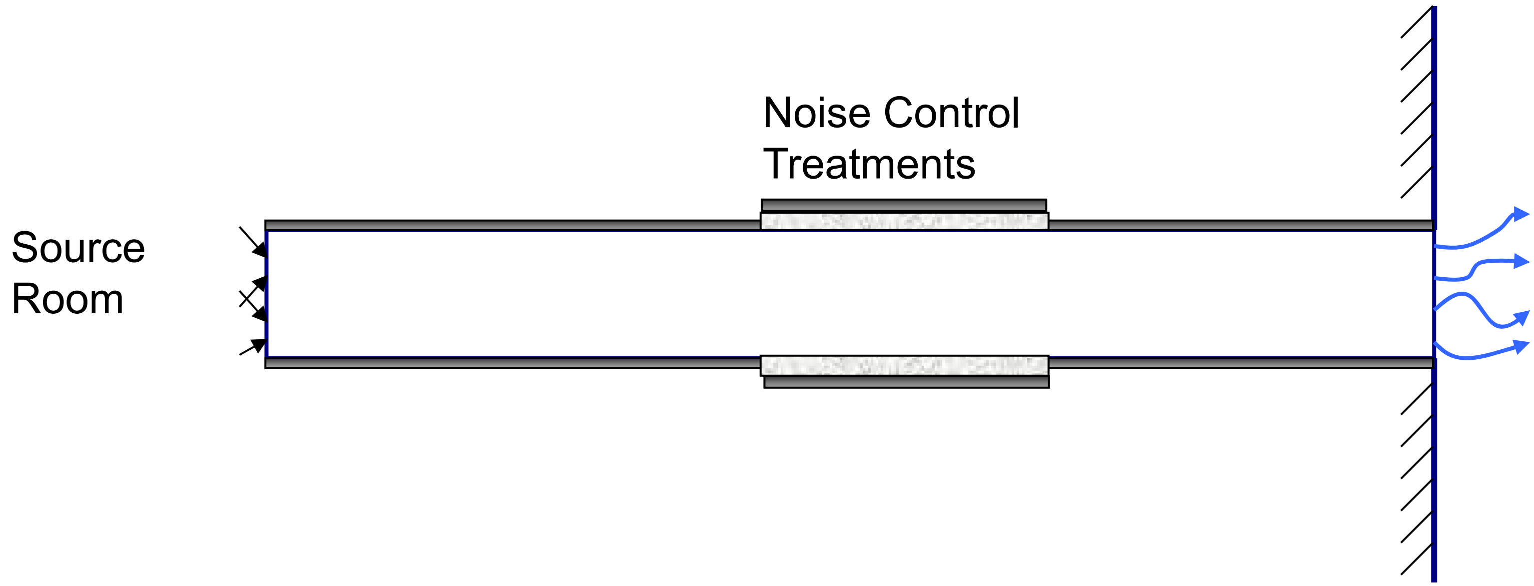
Sound Absorptive Material Properties





- Johnson-Champoux-Allard model (Allard and Atalla 2009)
- Curve fit (using ESI Foam-X software) used to identify the flow resistivity, characteristic viscous length, characteristic thermal length, and mass density for the fiber.
- Alternative sound absorbing models can be used with little impact.

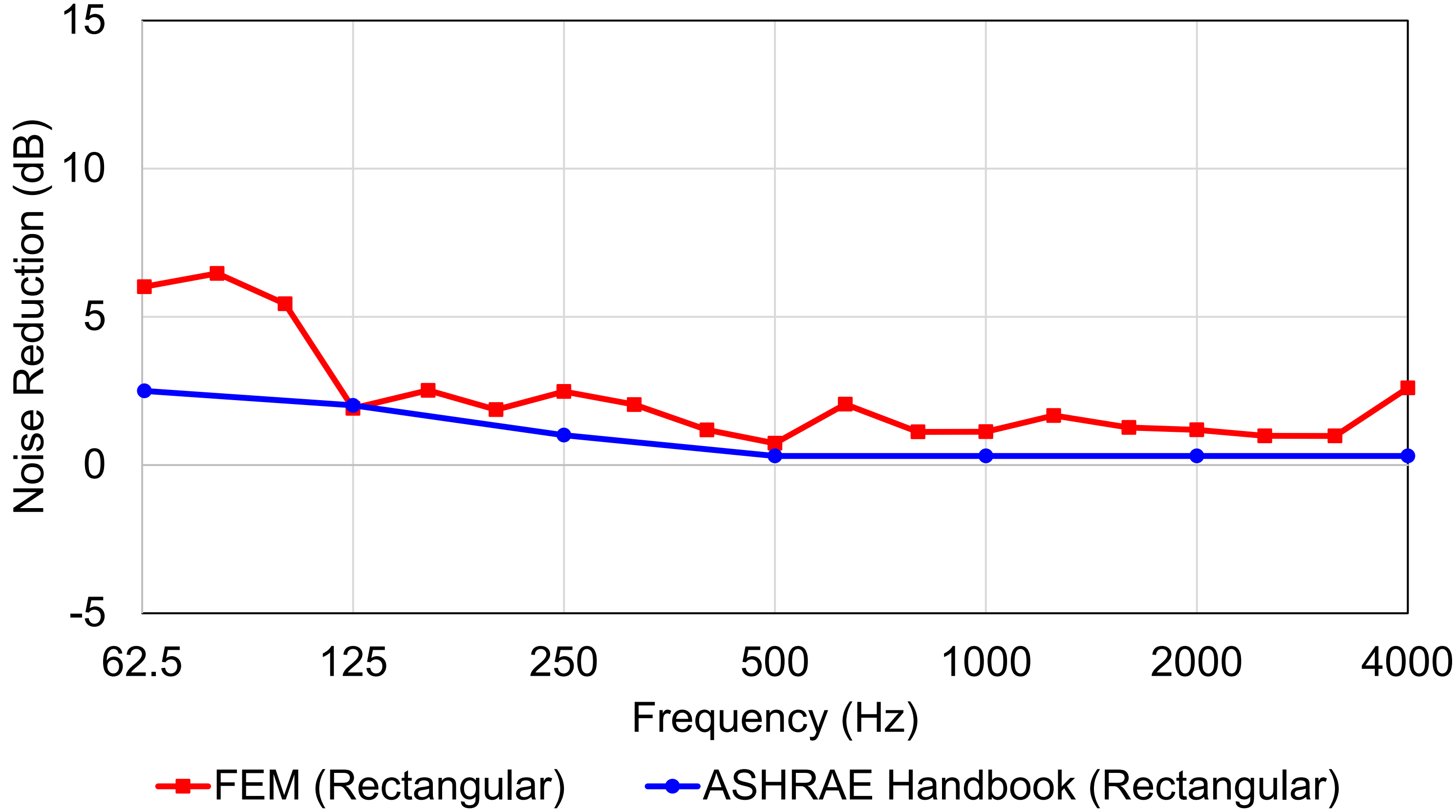
Metrics for Duct Attenuation



Insertion Loss – Difference in sound pressure level in receiving room without and with absorbing lining.
Noise Reduction – Difference in sound pressure level between source and termination (independent of source).
Transmission Loss – Difference between incident and transmitted sound power (independent of source and termination).

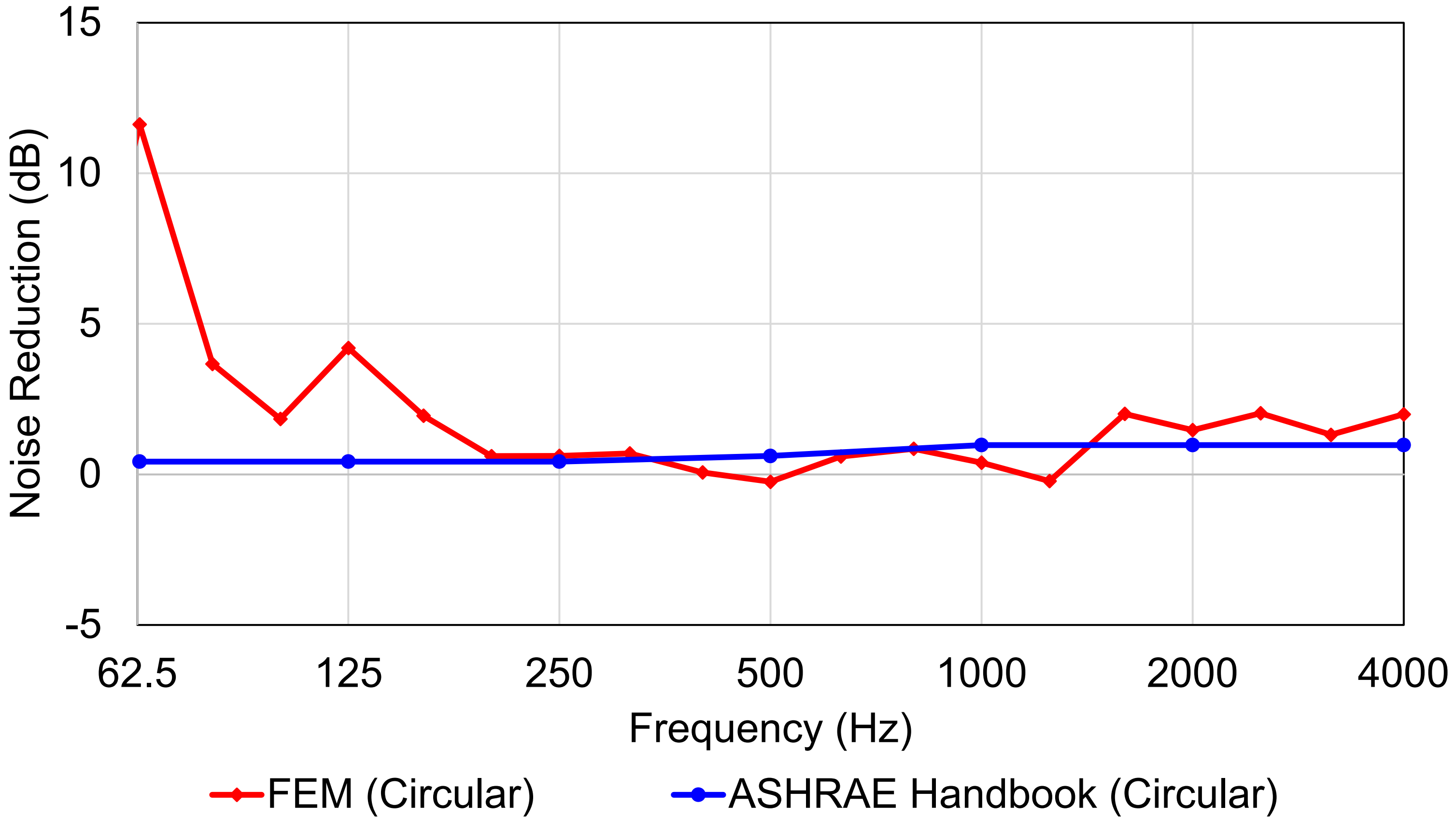
Noise Reduction – Unlined Duct

24 in x 24 in (0.61 m x 0.61 m), 10 ft (3.05 m) Length Square Duct



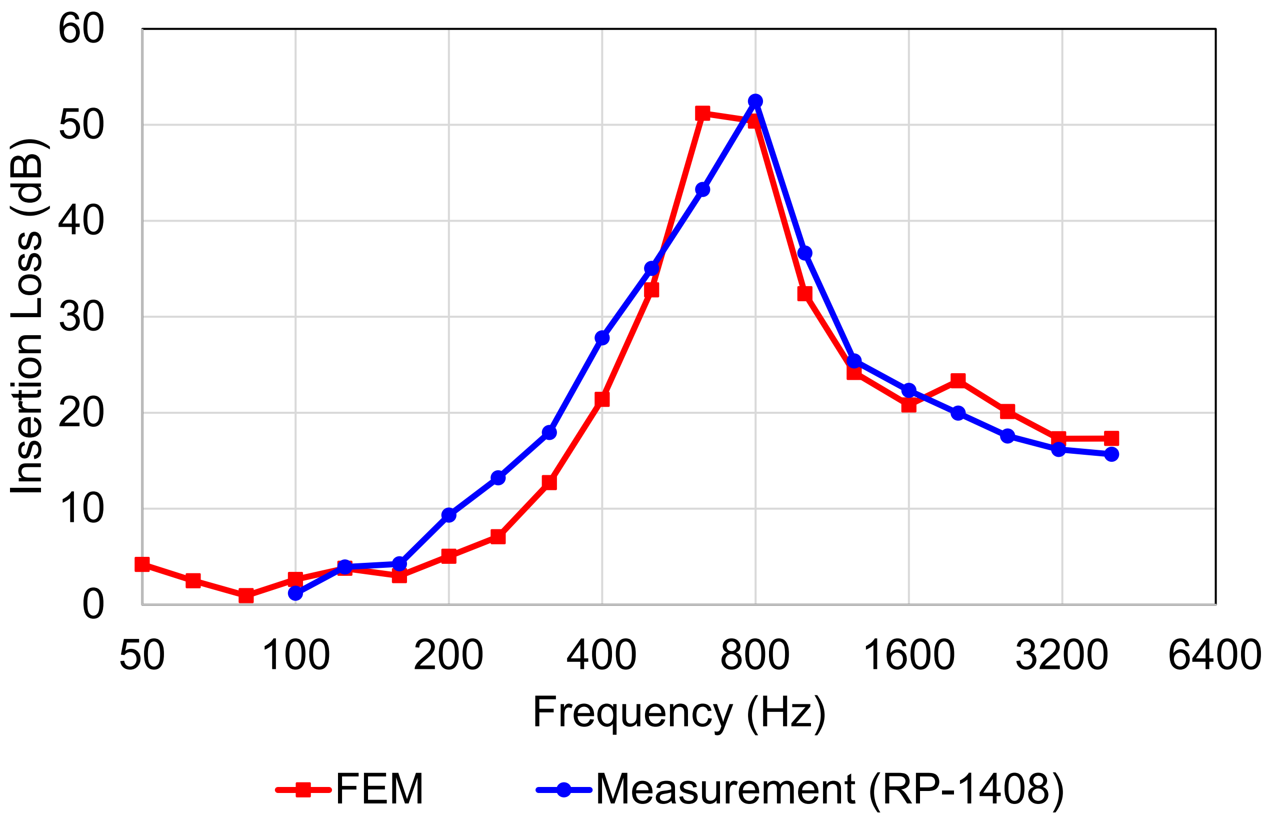
Noise Reduction – Unlined Duct

24 in (0.61 m) Diameter, 20 ft (6.10 m) Length Circular Duct

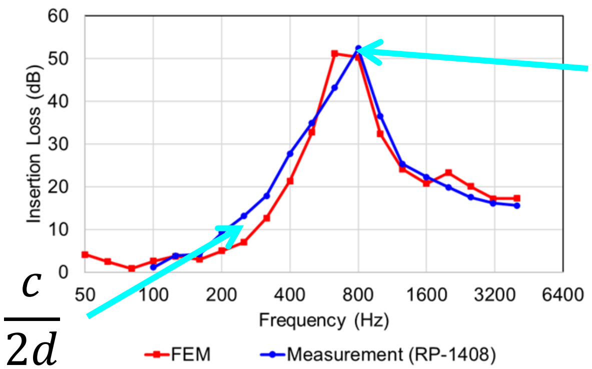


Insertion Loss – Lined Duct

24 in x 24 in (0.61 m x 0.61 m), 10 ft (3.05 m) Length Square Duct
2 in (5 cm) fiber lining)

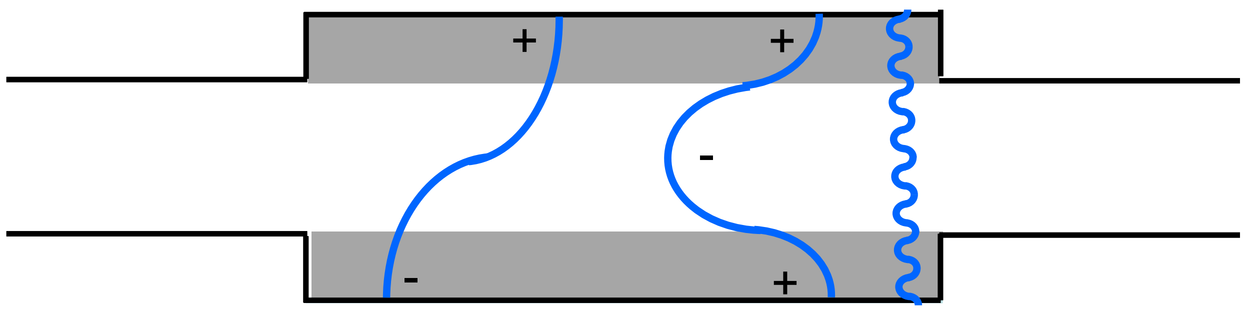


Insertion Loss – Lined Duct



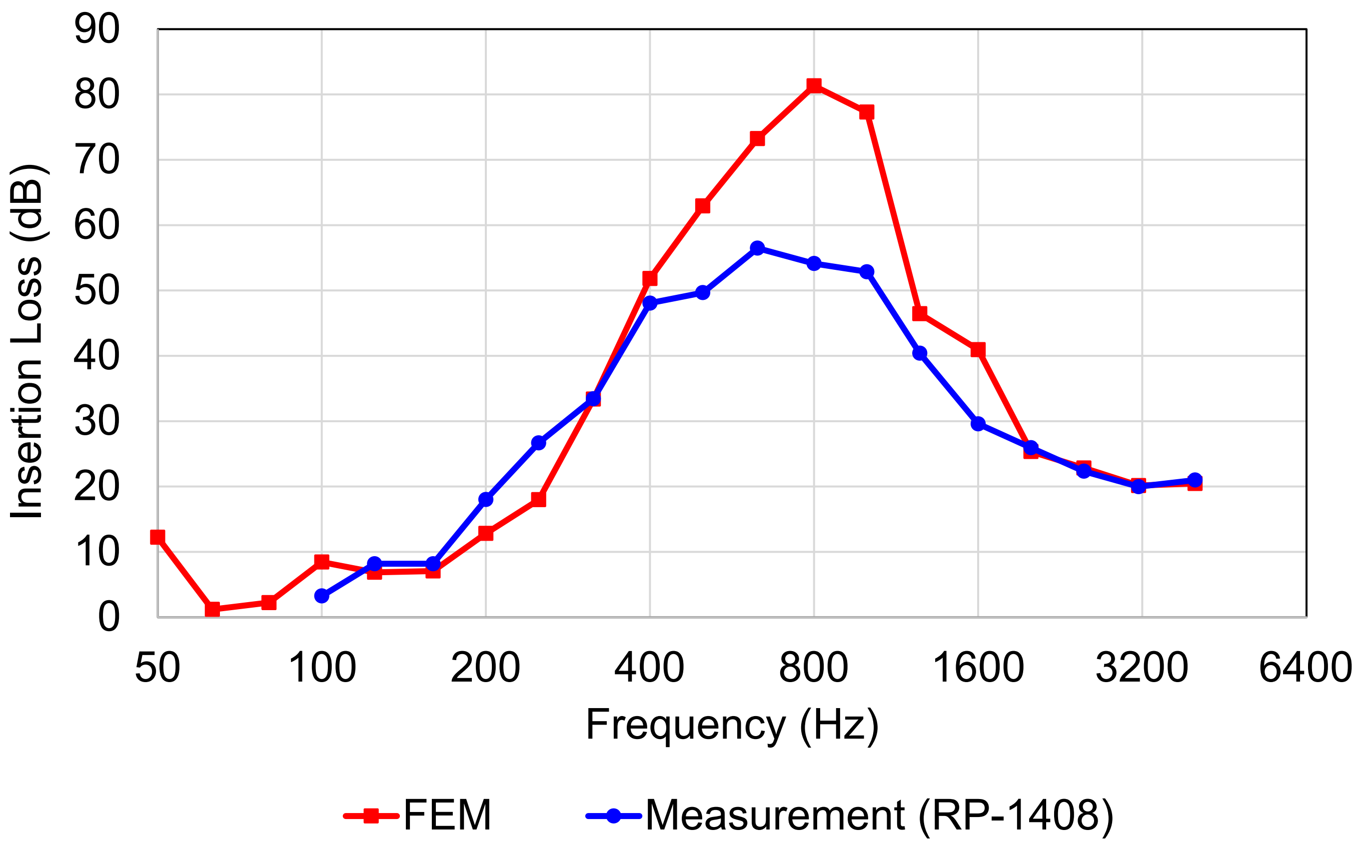
$$f_{max\ att} \approx \frac{c}{d}$$

$$f_{cutoff} = \frac{c}{2d}$$

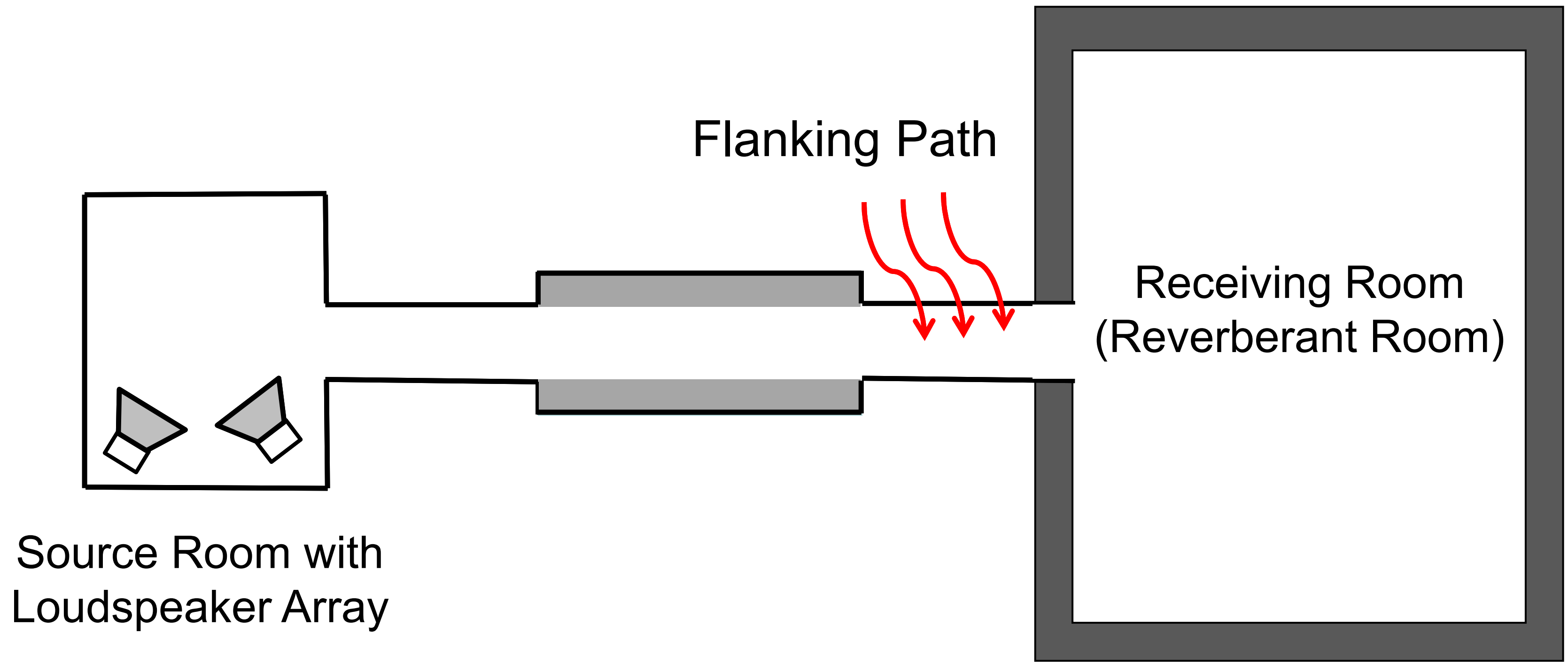


Insertion Loss – Lined Duct

24 in x 24 in (0.61 m x 0.61 m), 30 ft (9.15 m) Length Square Duct
2 in (5 cm) fiber lining)

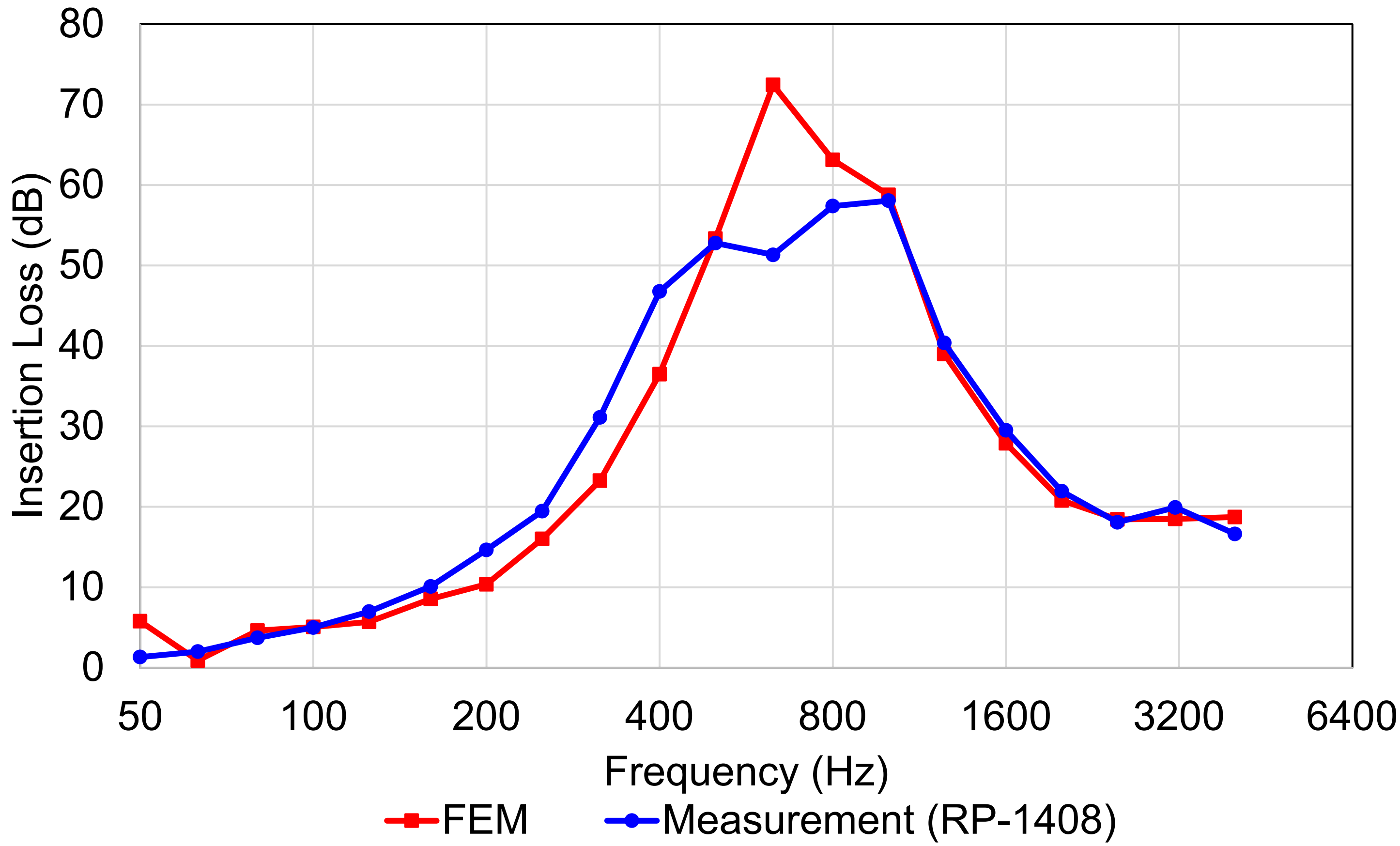


Likely Flanking Path

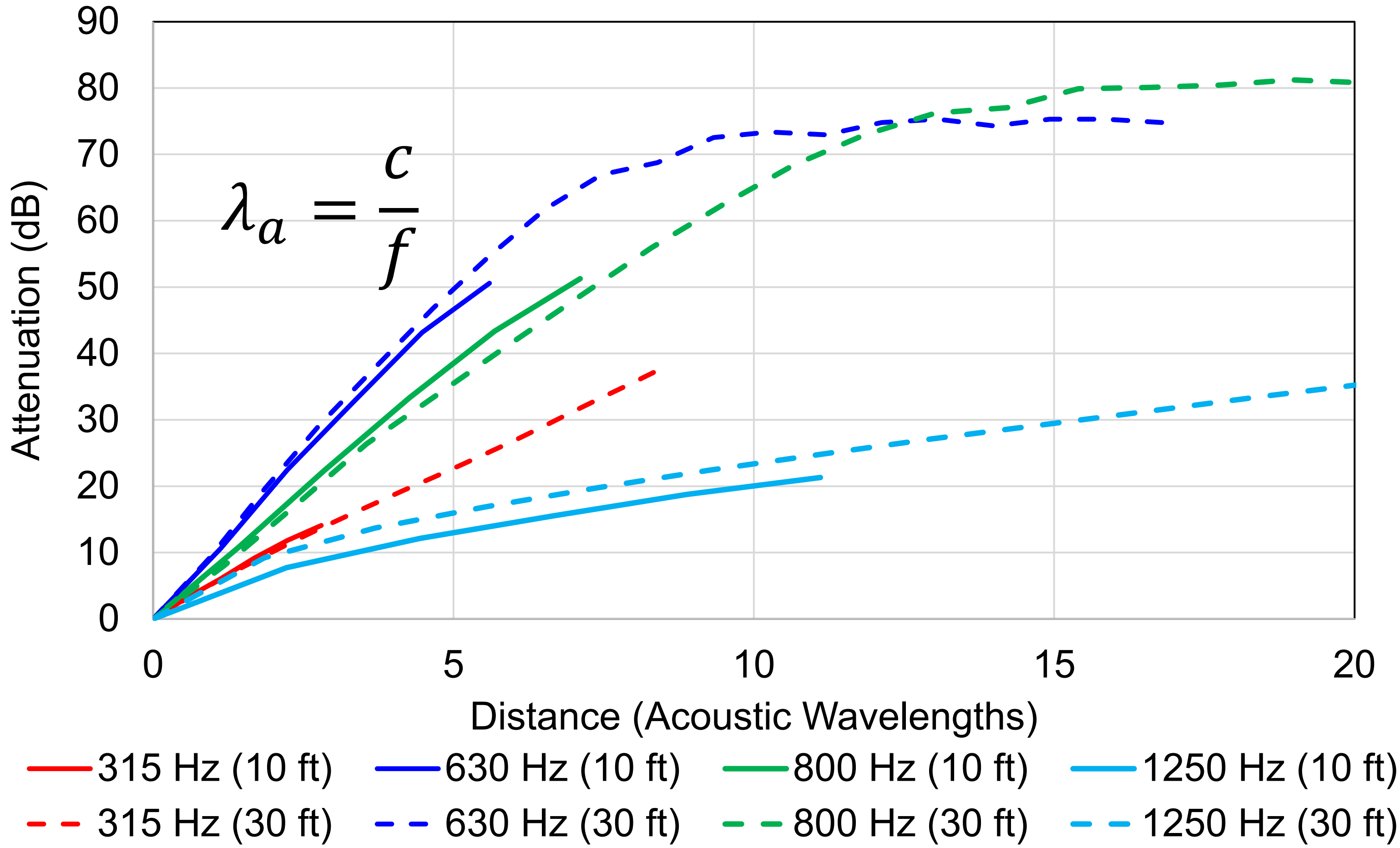


Insertion Loss – Lined Duct

24 in (0.61 m) Diameter, 20 ft (6.10 m) Length Circular Duct
2 in (5 cm) fiber lining)



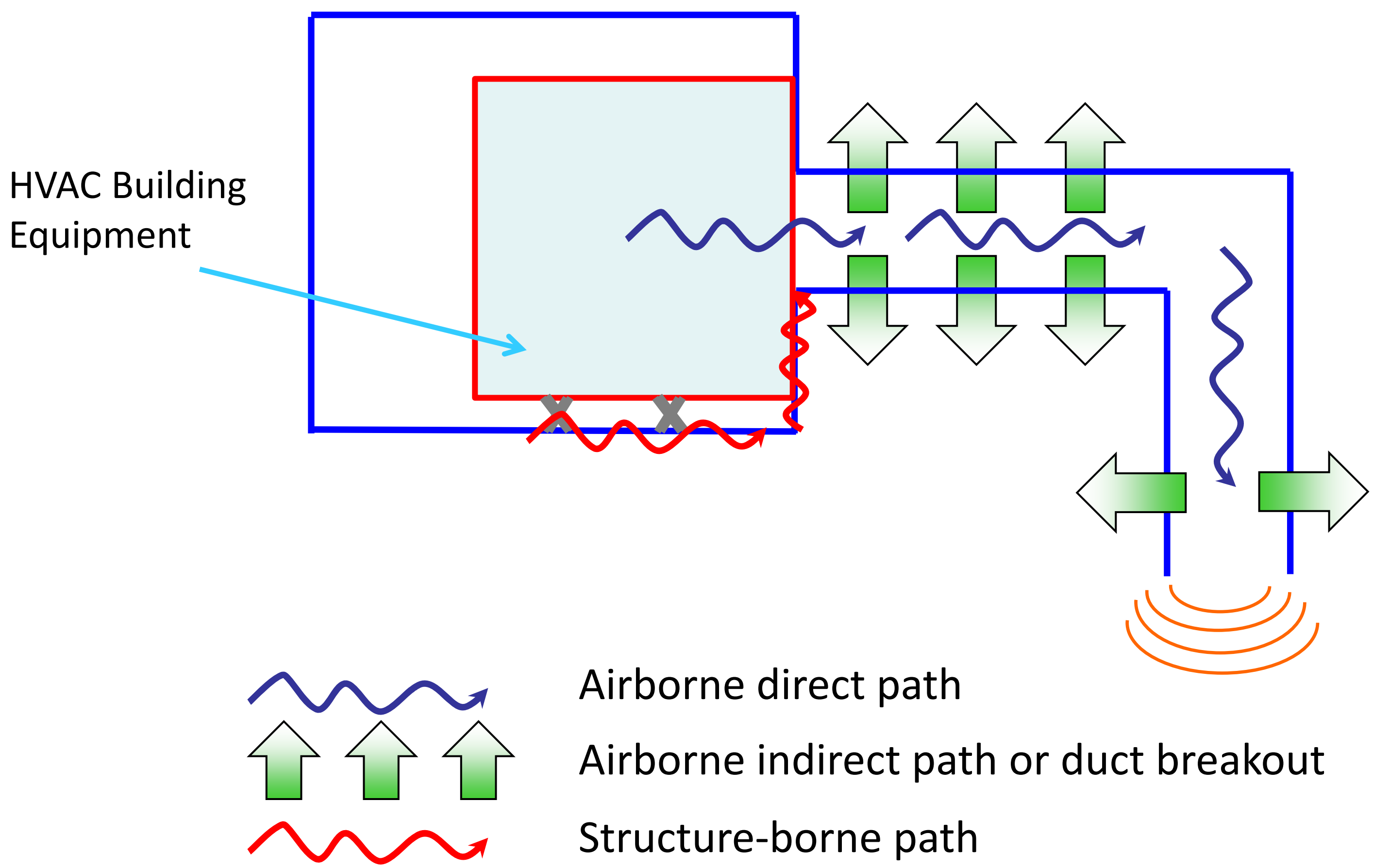
Attenuation vs. Length



Overview

- Unlined and Lined Duct Insertion Loss
- Elbow Insertion Loss
- Plenum Insertion Loss
- Duct Breakout Noise

Introduction

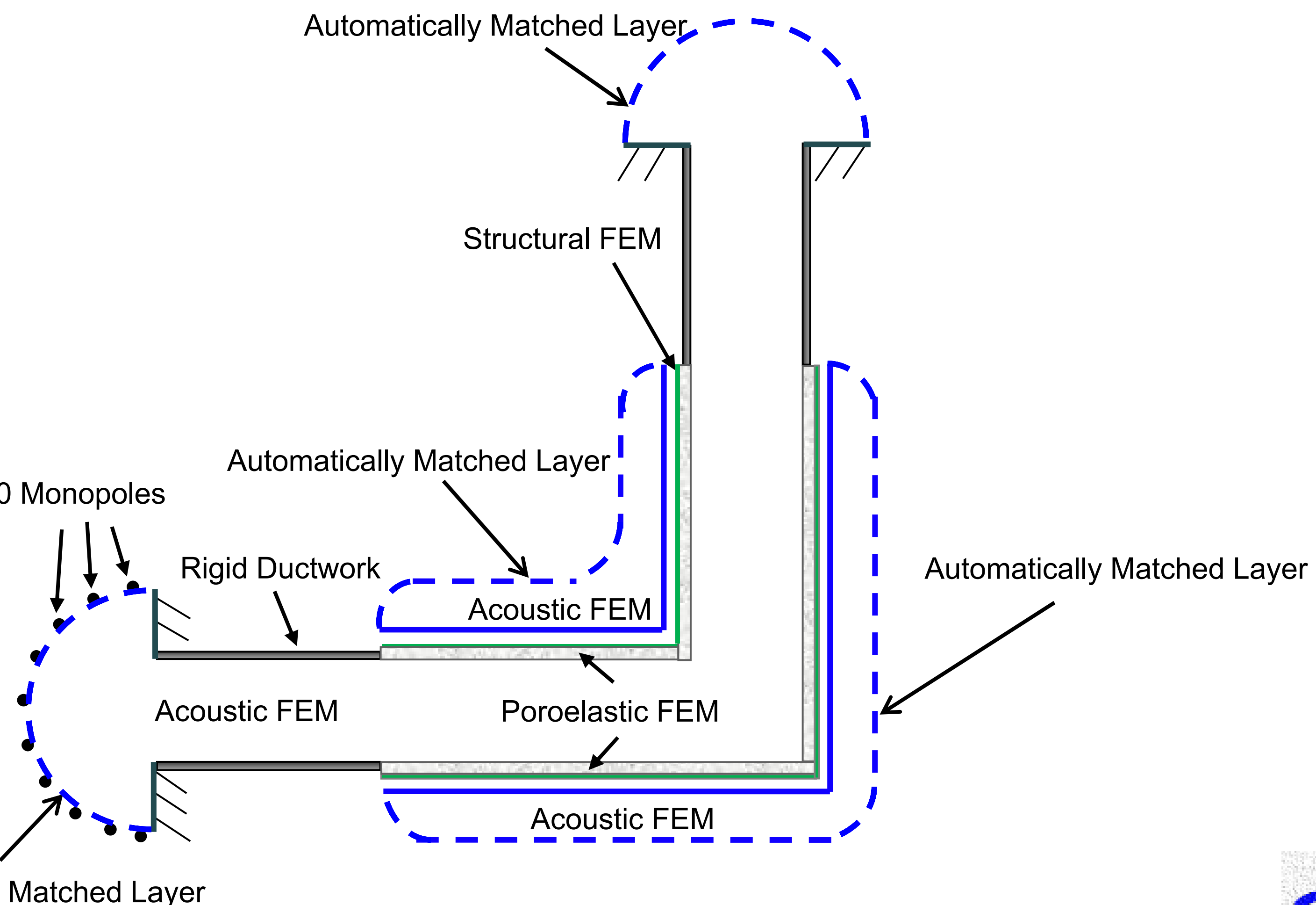


Prior Elbow Work

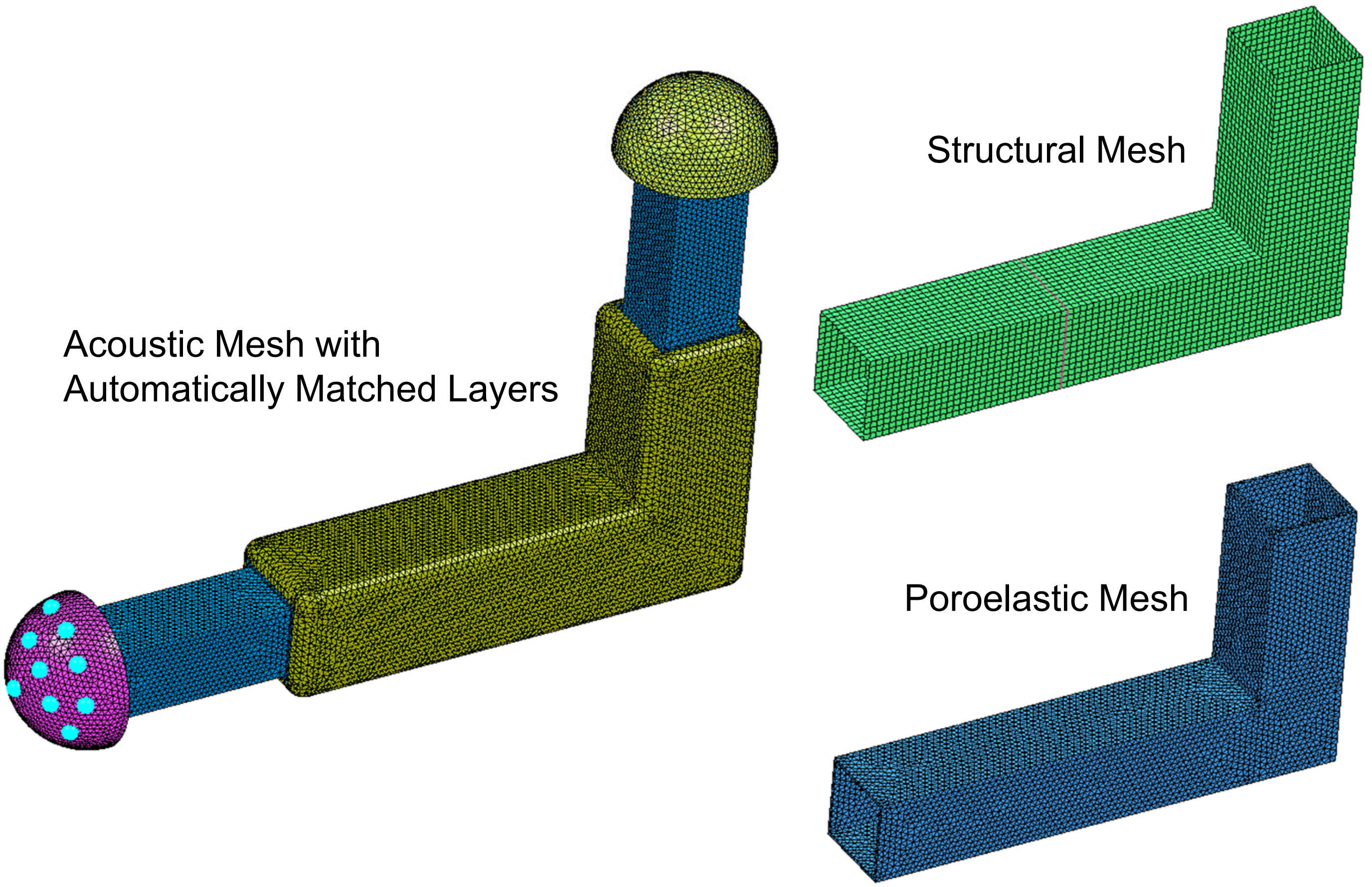
- Vér, I.L. 1983. Noise generation and noise attenuation of duct fittings – a review: Part II (RP-265). *ASHRAE Transactions* 90(2A):383-390.
- Mechel, F. 1975. Mufflers, Chapter 19, Pocket Book of Technical Acoustics. Ed. H. Heckl and M.A. Mueller, Springer (in German).
- VDI.2001. VDI Technical Report 2081. *Noise Generation and Noise Reduction in Air-Conditioning Systems*.

Limitation Studies limited to certain duct sizes, bend angles, and specific sound absorptive linings.

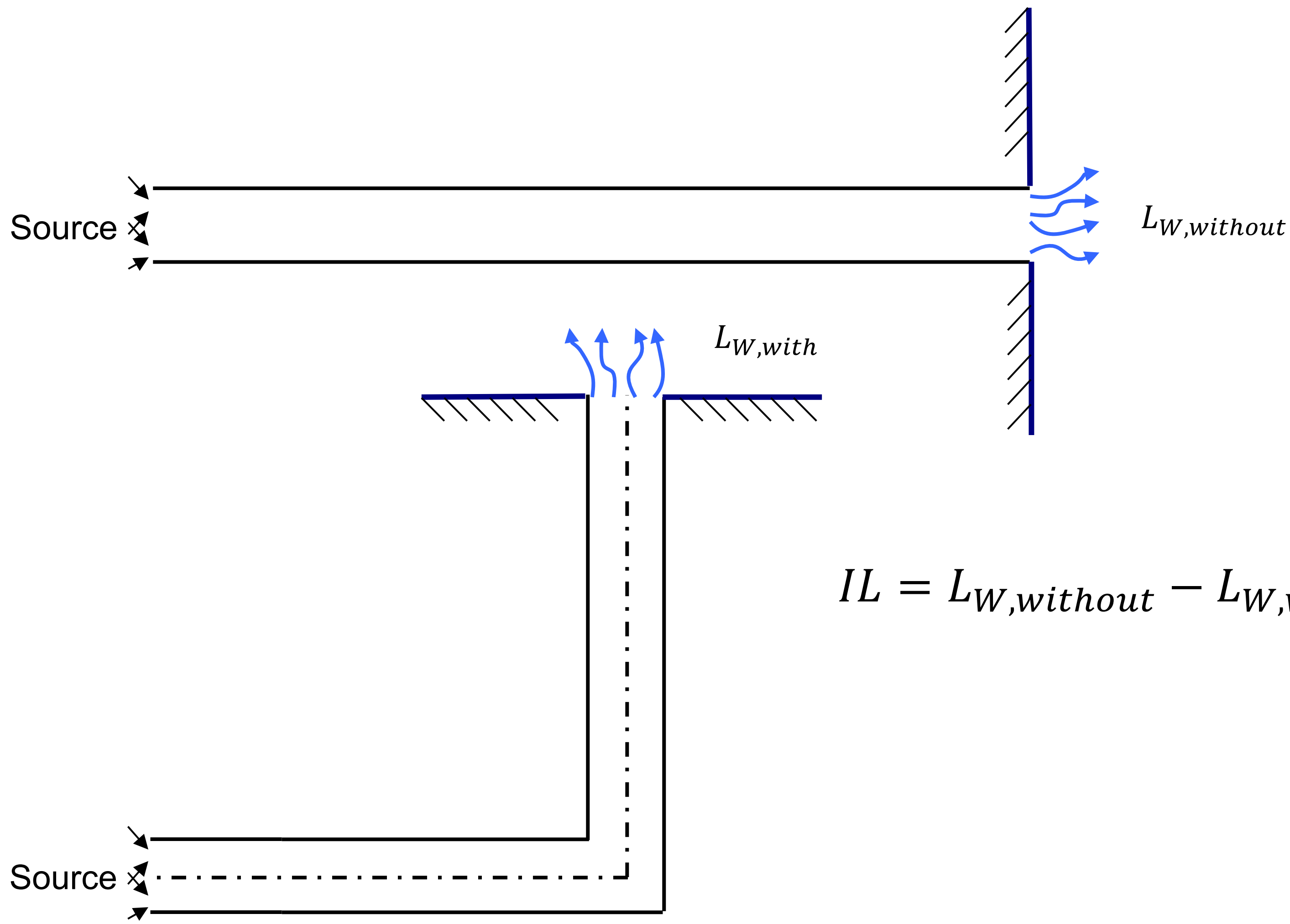
Modeling Approach



Modeling Approach



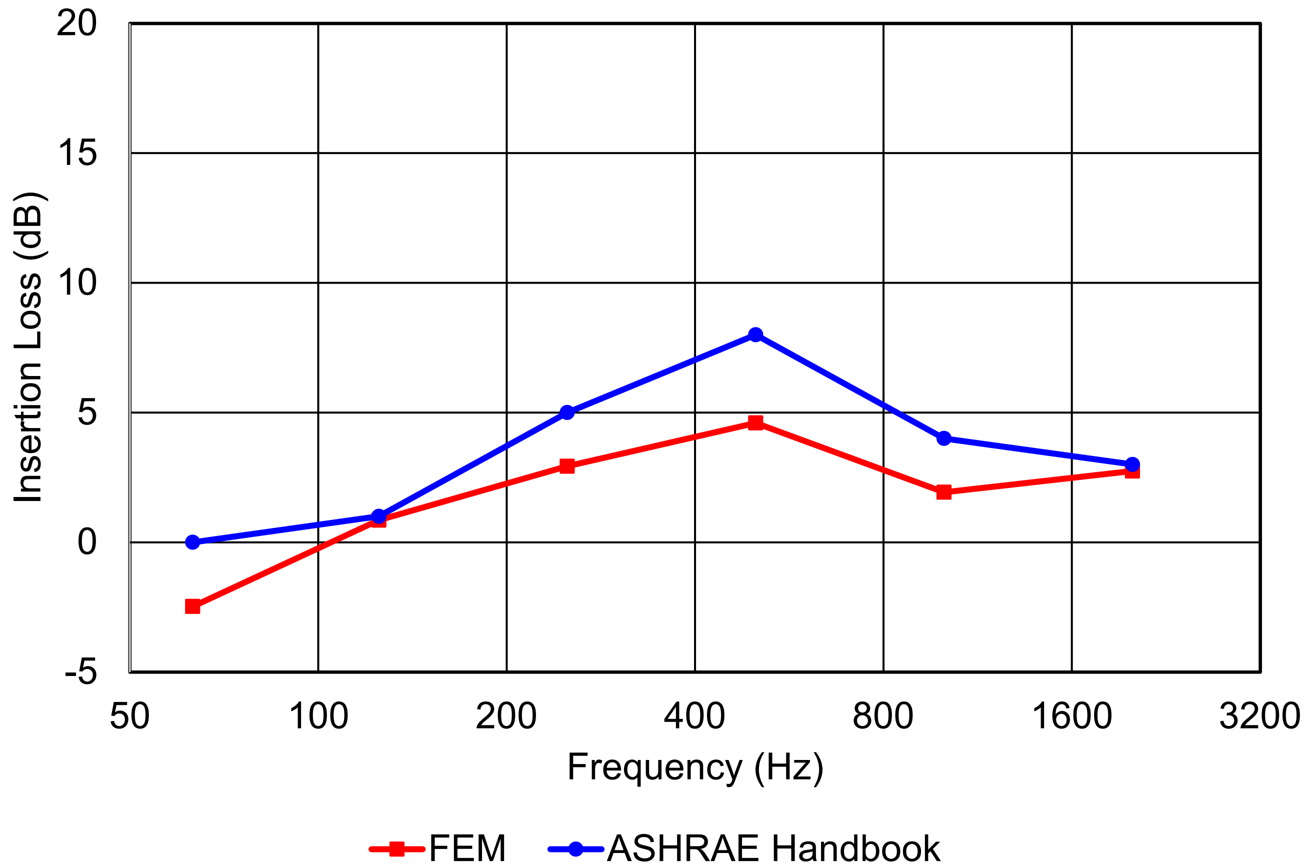
Elbow Insertion Loss



$$IL = L_{W,without} - L_{W,with}$$

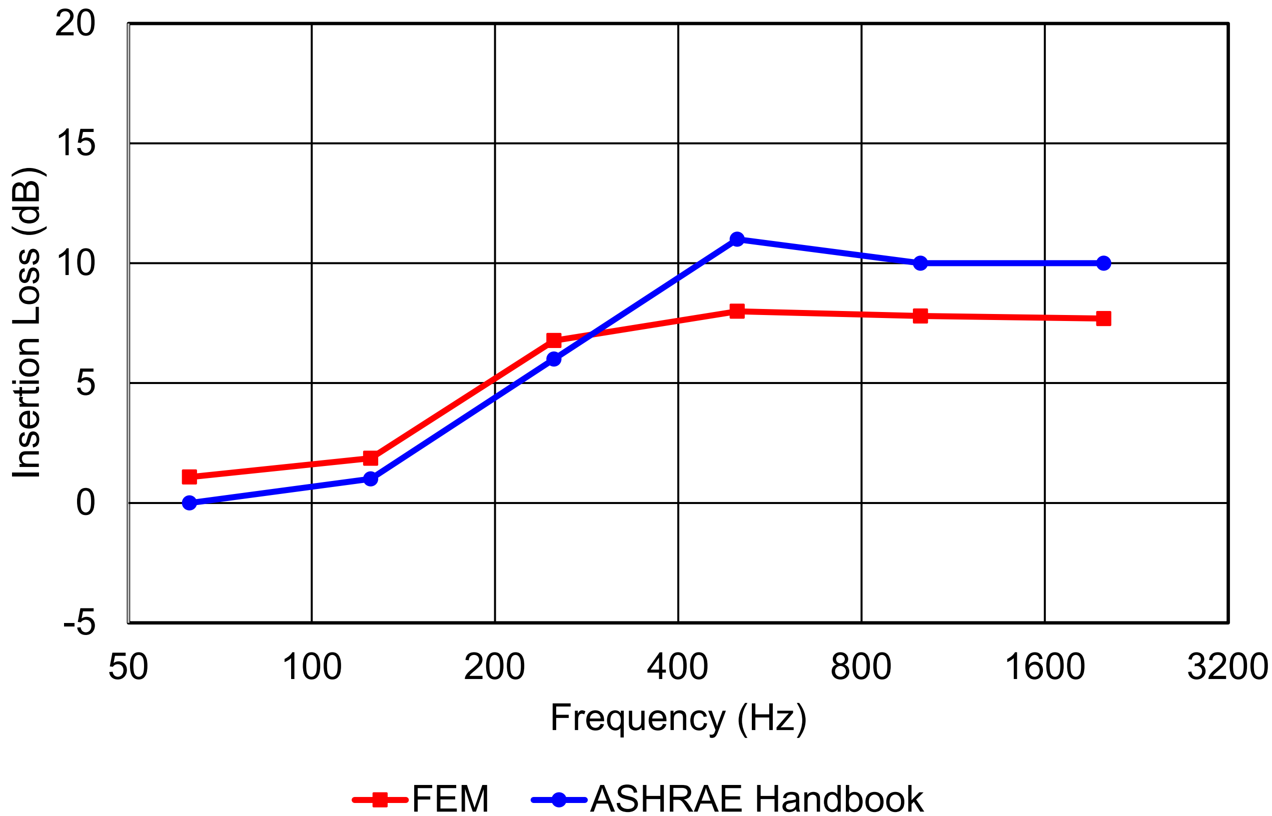
Insertion Loss – Unlined Elbow

24 in x 24 in (0.61 m x 0.61 m)

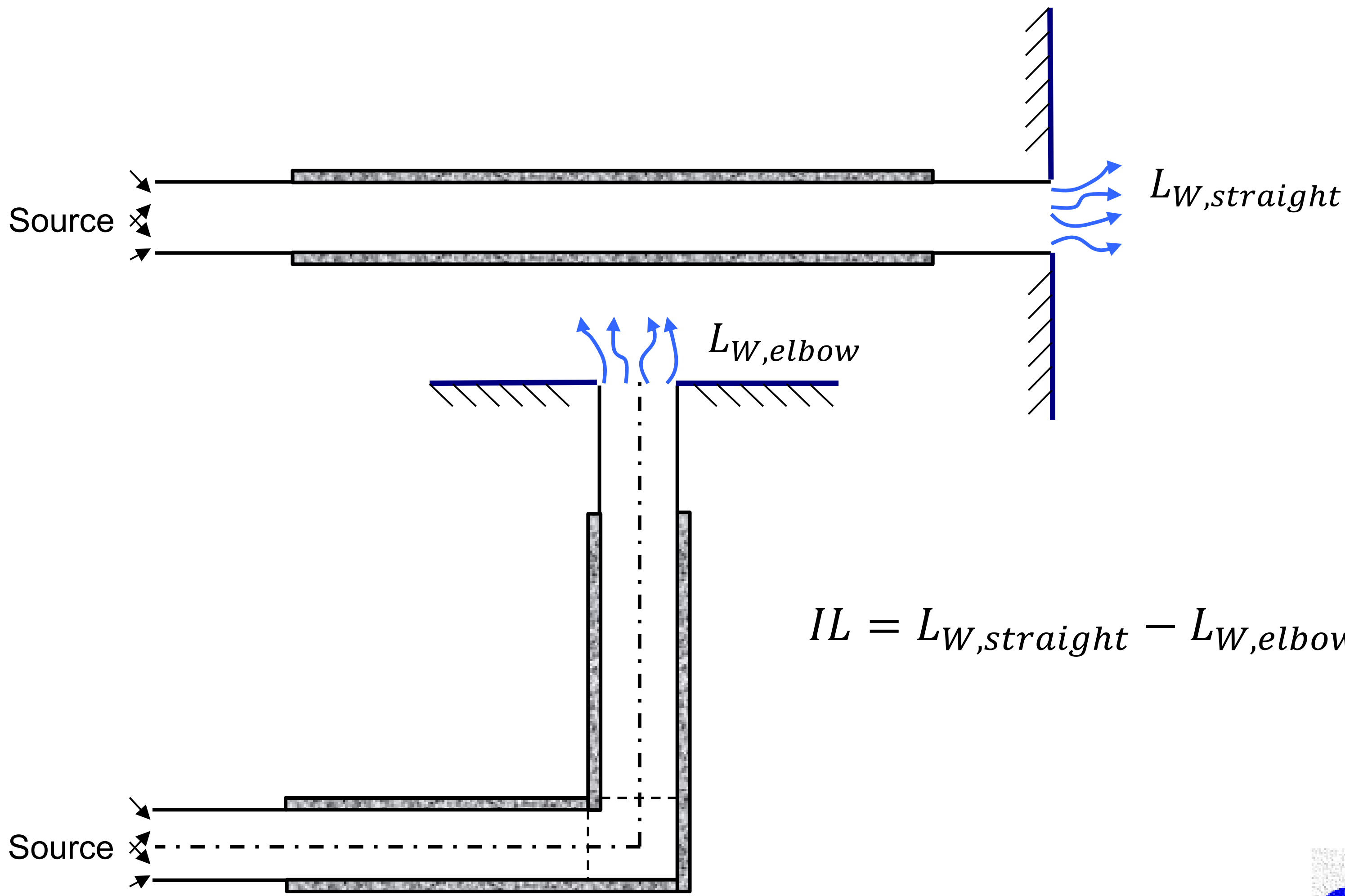


Insertion Loss – Lined Elbow

24 in x 24 in (0.61 m x 0.61 m)
1 in (2.5 cm) fiber lining



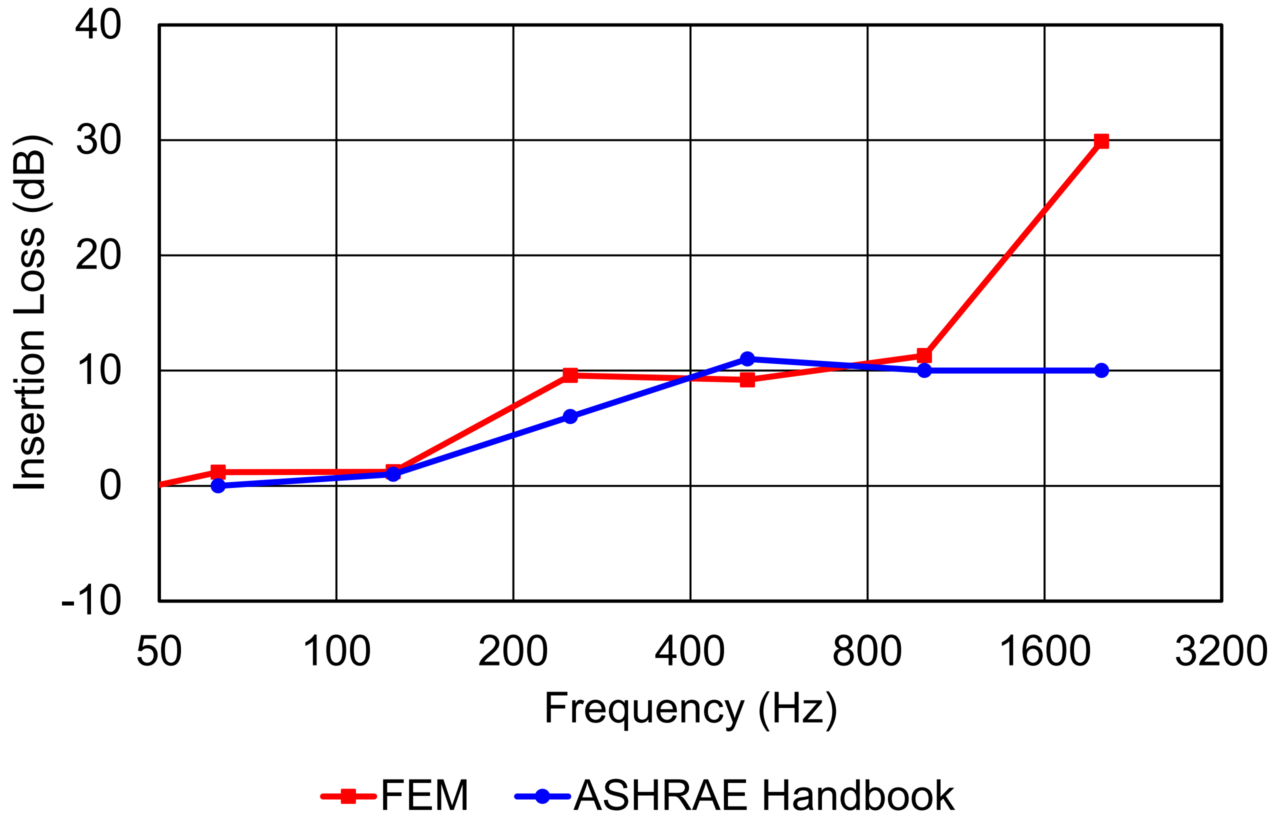
Lined Elbow Insertion Loss



$$IL = L_{W,straight} - L_{W,elbow}$$

Insertion Loss – Lined Elbow

24 in x 24 in (0.61 m x 0.61 m)
1 in (2.5 cm) fiber lining

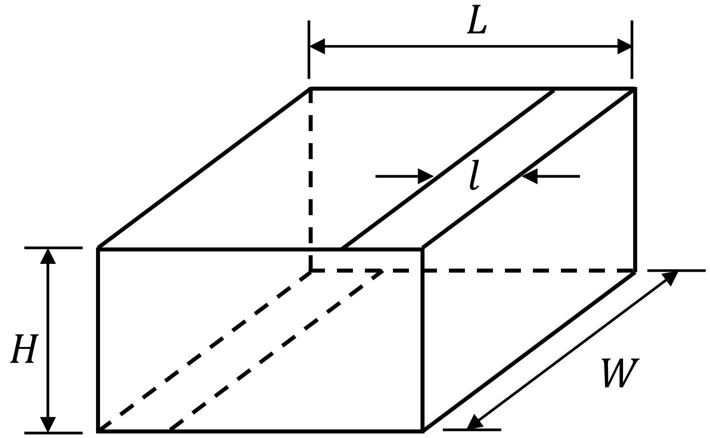


Overview

- Lined Duct Insertion Loss
- Elbow Insertion Loss
- Plenum Insertion Loss
- Duct Breakout Noise

Unlined and Lined Plenums

Wells, 1958



Above the cutoff frequency

$$IL = 10\log_{10}\left(S_{out}\left(\frac{cos\theta}{2\pi d^2} + \frac{1}{R}\right)\right)^{-1}$$

$$S_{out} = lW$$

$$R = S\alpha/(1-\alpha))$$

$$d = \sqrt{(L-l)^2 + H^2})$$

$$\cos\theta = H/d$$

Unlined and Lined Plenums

Mouratides and Becker, 2003

Below the cutoff frequency

$$IL = A_f S + W_e + E_{oa}$$

A_f ~ empirically defined surface area coefficient

S ~ total inside surface area of plenum less the inlet and outlet areas

W_e ~ wall effect (dB)

E_{oa} ~ offset angle effect (dB)

Unlined and Lined Plenums

Mouratides and Becker, 2003

Above the cutoff frequency

$$IL = b\left(\frac{S_{out}Q}{4\pi r^2} + \frac{S_{out}(1-\alpha_a)}{S\alpha_a}\right)^n + E_{oa}$$

S_{out} ~ outlet cross-sectional area

S ~ surface area of the plenum

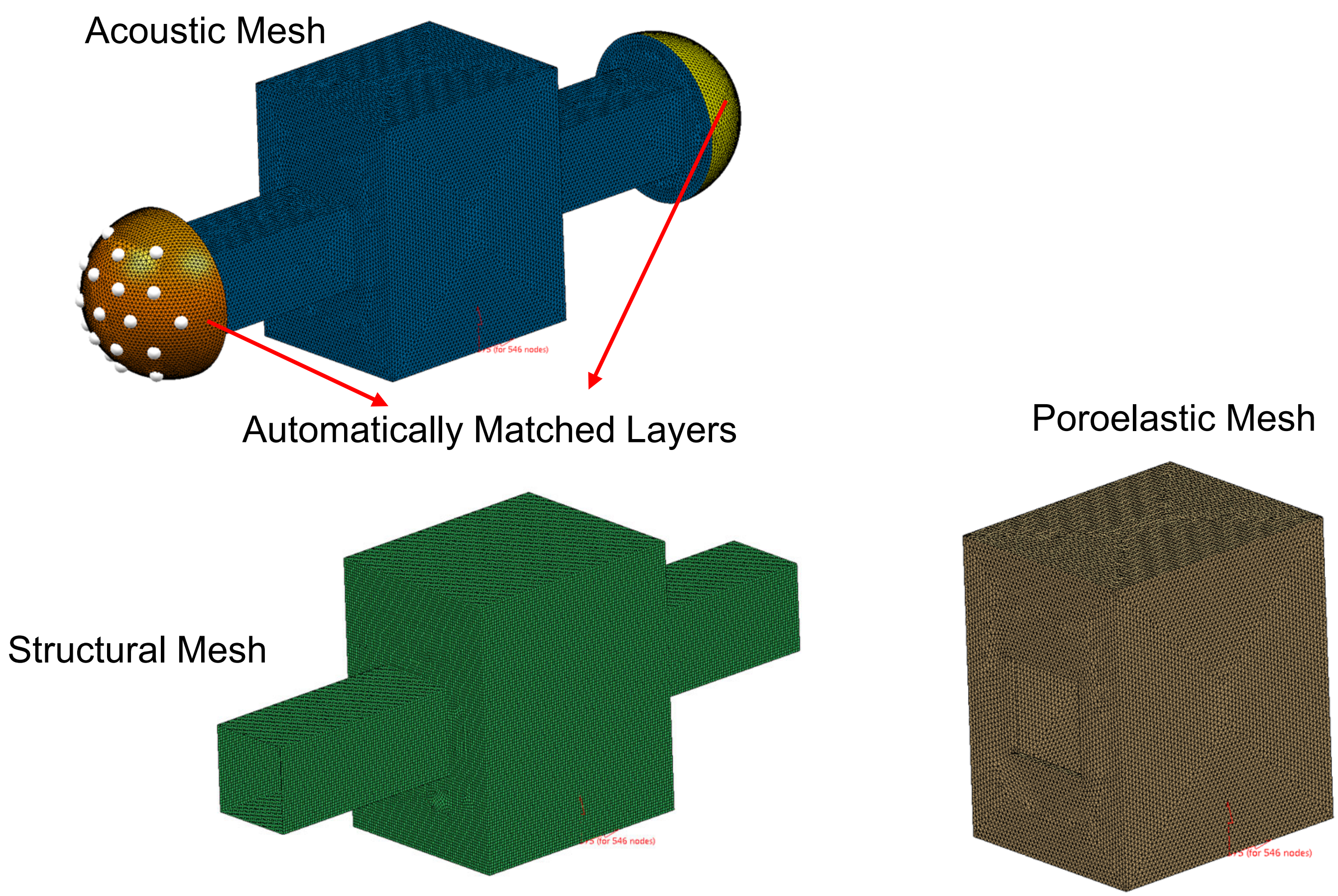
r ~ distance between the centers of the inlet and outlet sections

Q ~ directivity factor, and α_a is the average absorption coefficient in the plenum

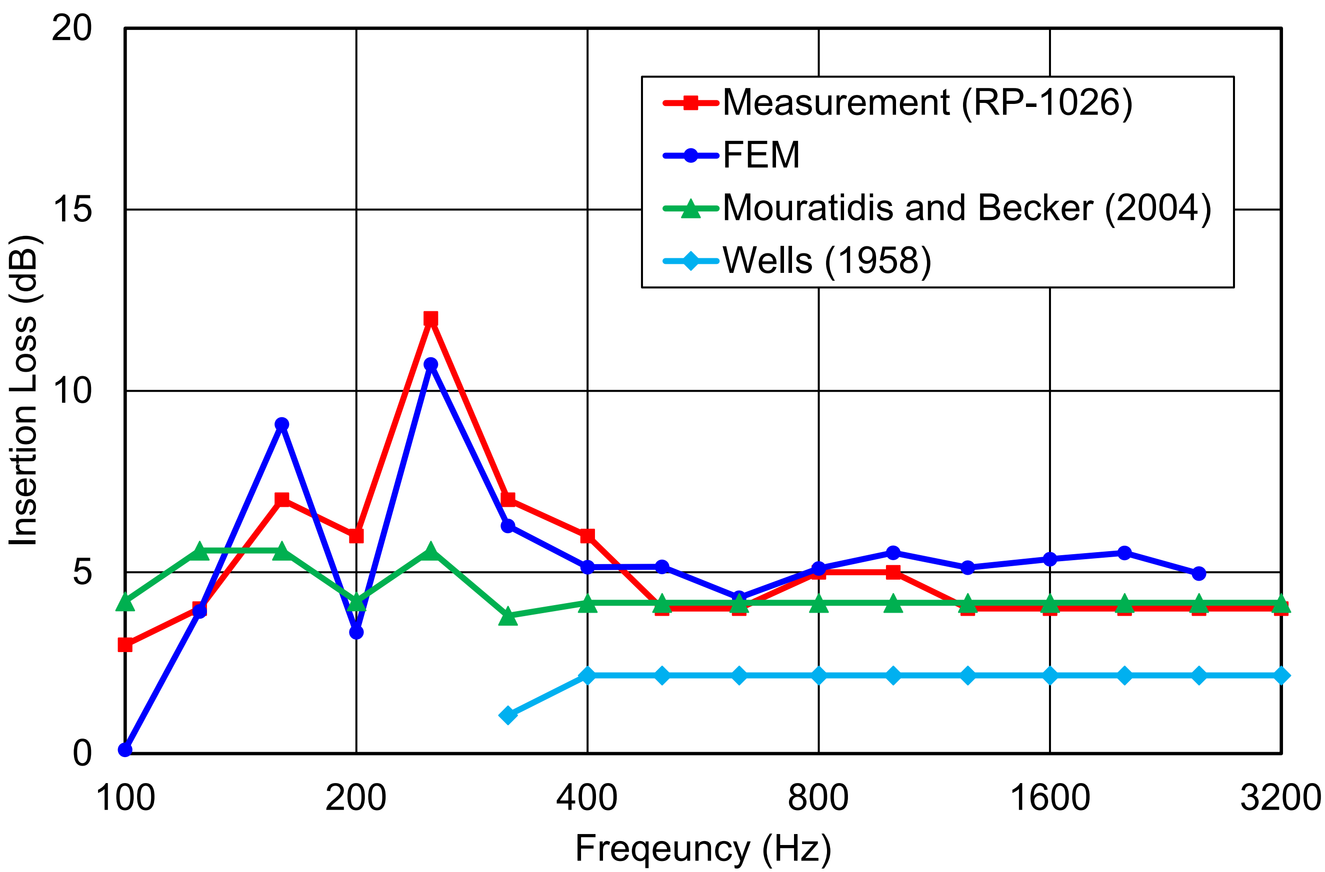
b, n ~ empirically determined constants (3.505 and -0.359)

E_{oa} ~ offset angle effect (dB)

Finite Element Model



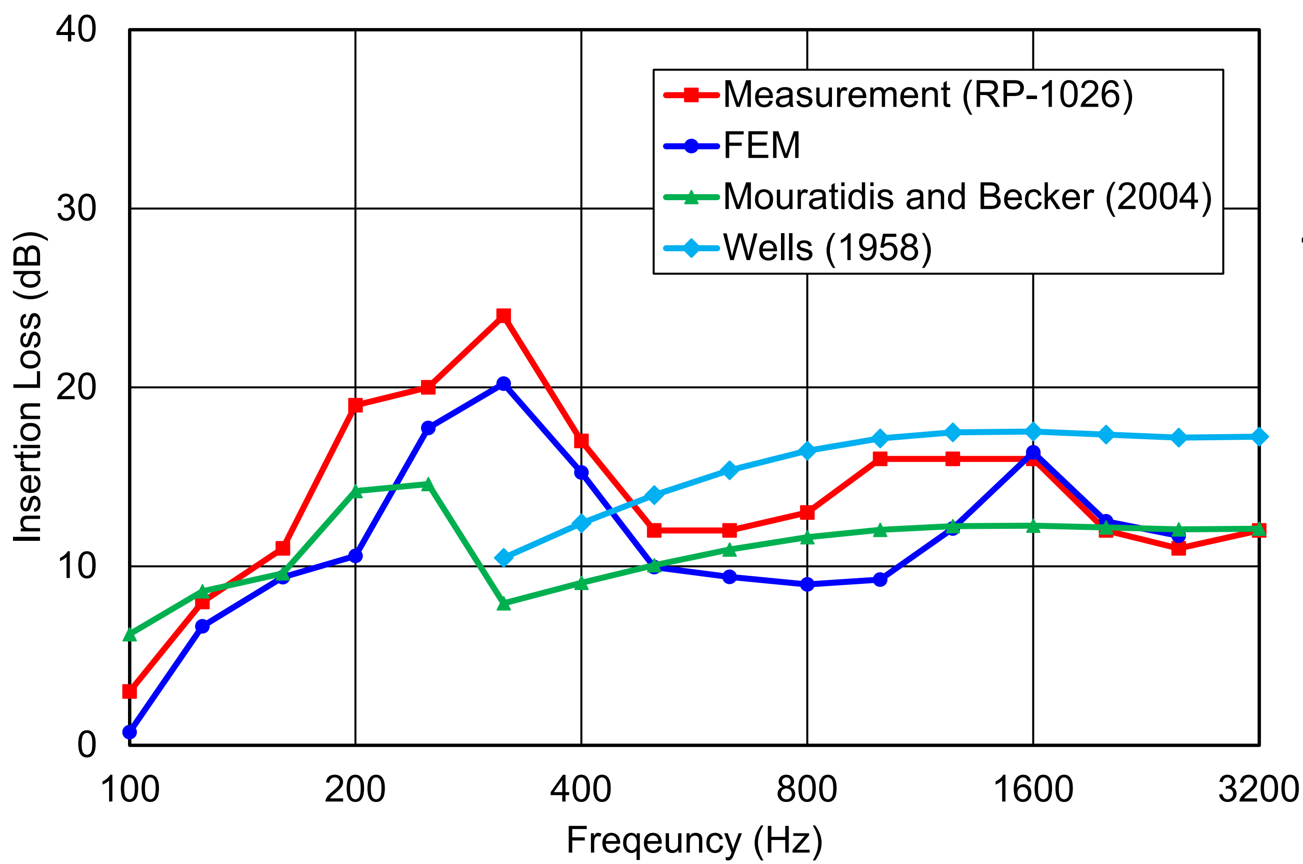
Insertion Loss – Unlined Plenum



4 ft x 6 ft x 5 ft

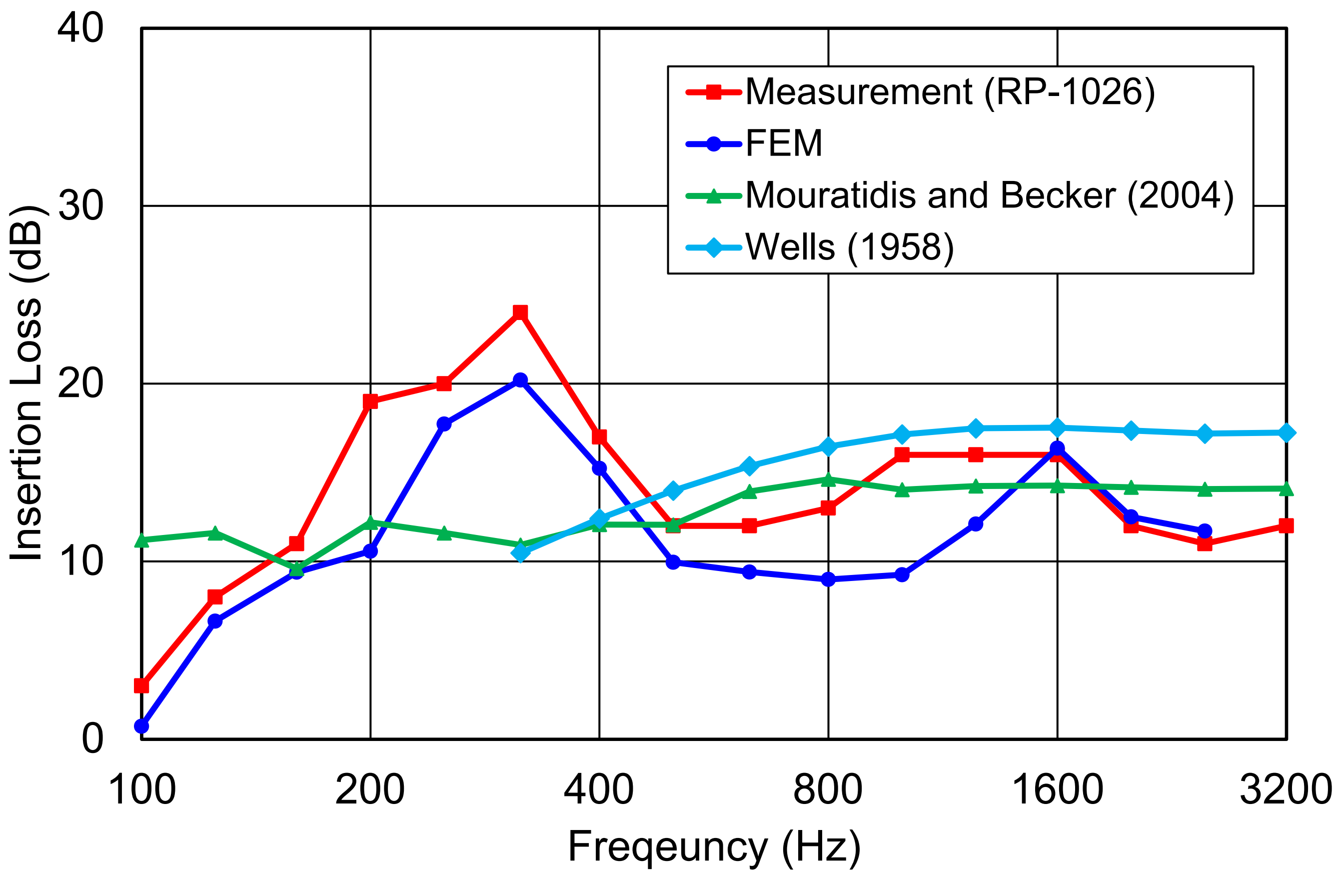
unlined plenum

Insertion Loss – Lined Plenum



4 ft x 6 ft x 5 ft lined (2 in fiber) plenum

Insertion Loss – Lined Plenum with Right Angle



4 ft x 6 ft x 5 ft lined

(2 in fiber) plenum

Inlet and outlet ducts at right angles

Overview

- Lined Duct Insertion Loss
- Elbow Insertion Loss
- Plenum Insertion Loss
- Duct Breakout Noise

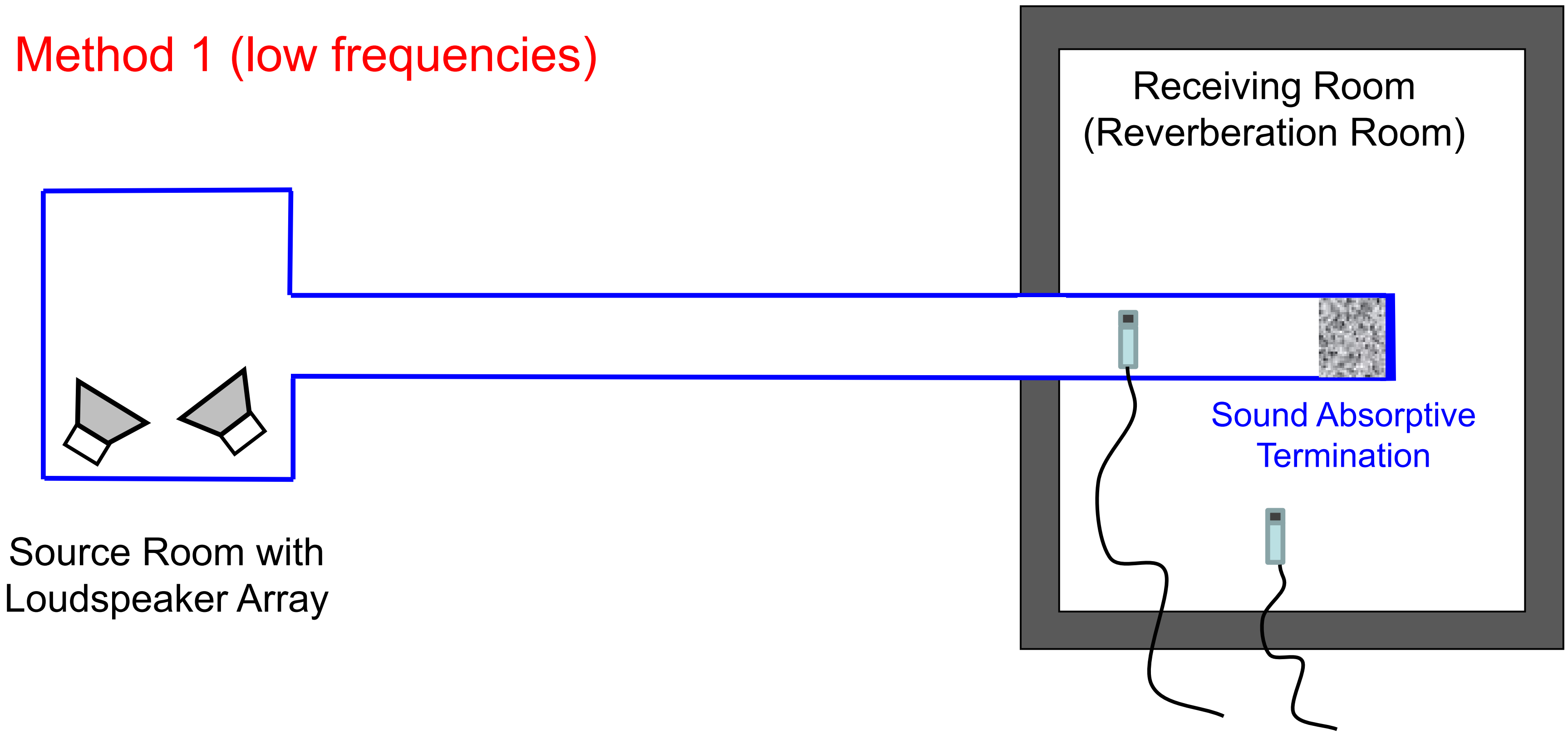
Prior Breakout TL Work

- Vér, I.L. 1983. *Prediction of Sound Transmission through Duct Walls; Breakout and Pickup*. ASHRAE TRP-319.
- Cummings, A. 1983. Acoustic noise transmission through the walls of air conditioning ducts. *Final Report*, Department of Mechanical and Aerospace Engineering, University of Missouri, Rolla.
- Cummings, A. 1985. Acoustic noise transmission through duct walls. *ASHRAE Transactions* 91(2A):48-61.
- Cummings, A. 2001. Sound transmission through duct walls. *Journal of Sound and Vibration* 239(4):731-765.
- Lilly, J. 1987. Breakout in HVAC duct systems. *Sound & Vibration* 21(10).

Limitation Studies limited to certain duct sizes and specific sound absorptive linings.

Measurement (Cummings, 1985)

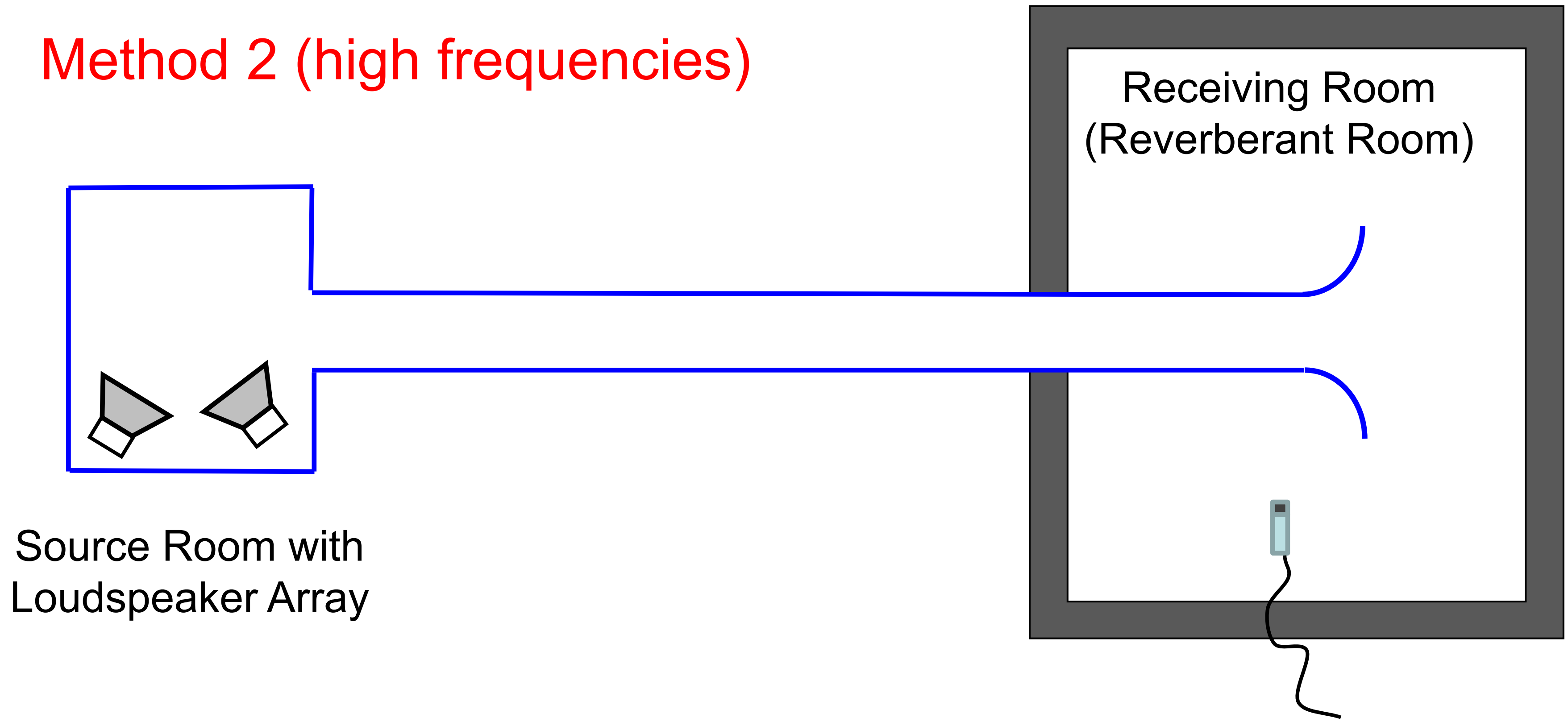
Method 1 (low frequencies)



$$TL_{out} = L_{W(in)} - L_{W(out)} + 10\log_{10}\left(\frac{S_{rad}}{S}\right)$$

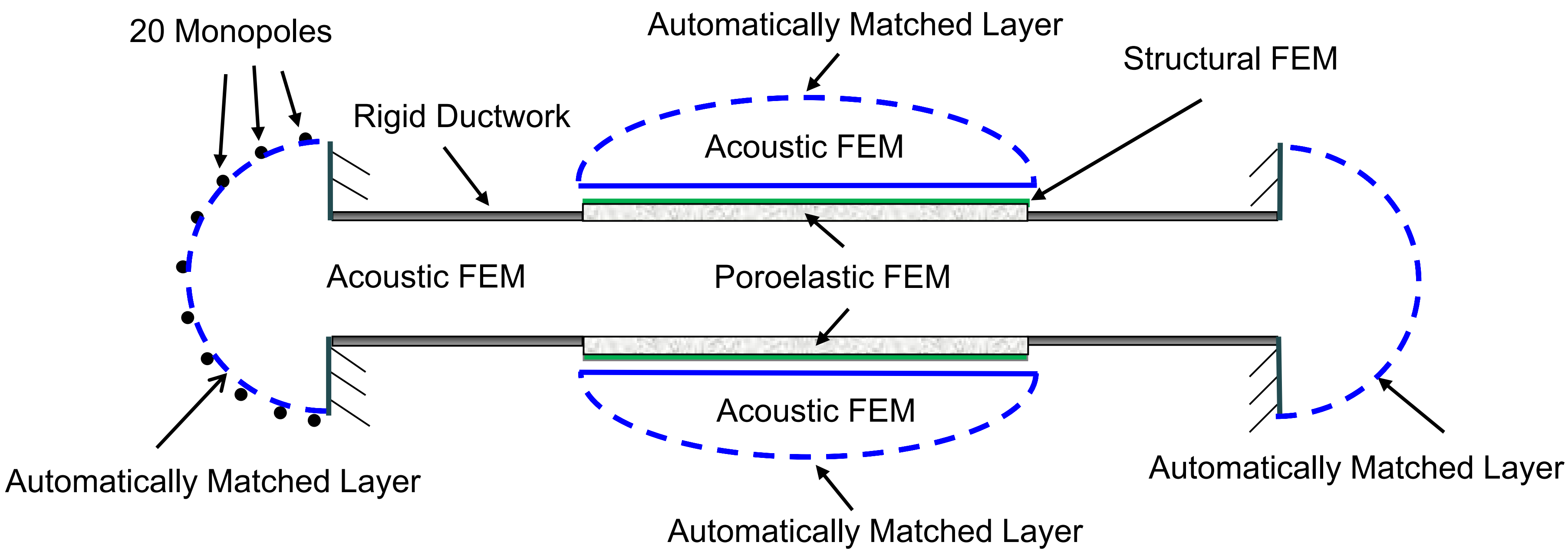
Measurement (Cummings, 1985)

Method 2 (high frequencies)

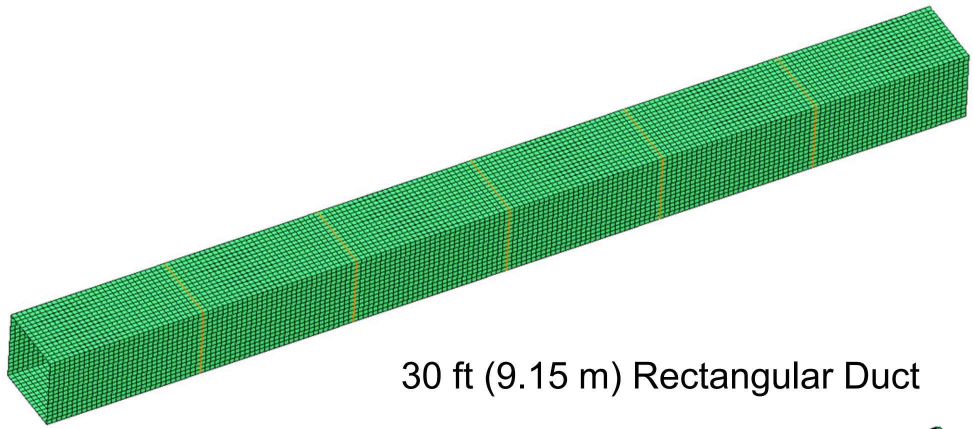


Measure sound pressure in reverberation room with cap as on prior slide then measure again with horn.

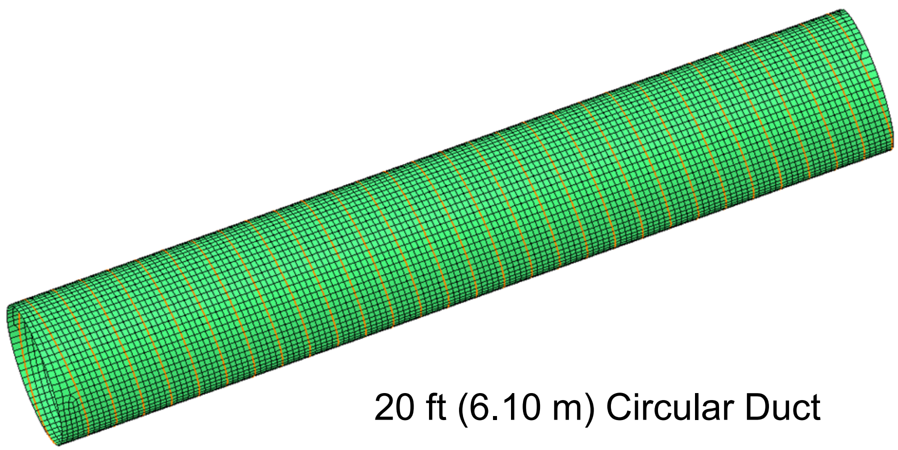
Modeling Approach



Structural FEM Models

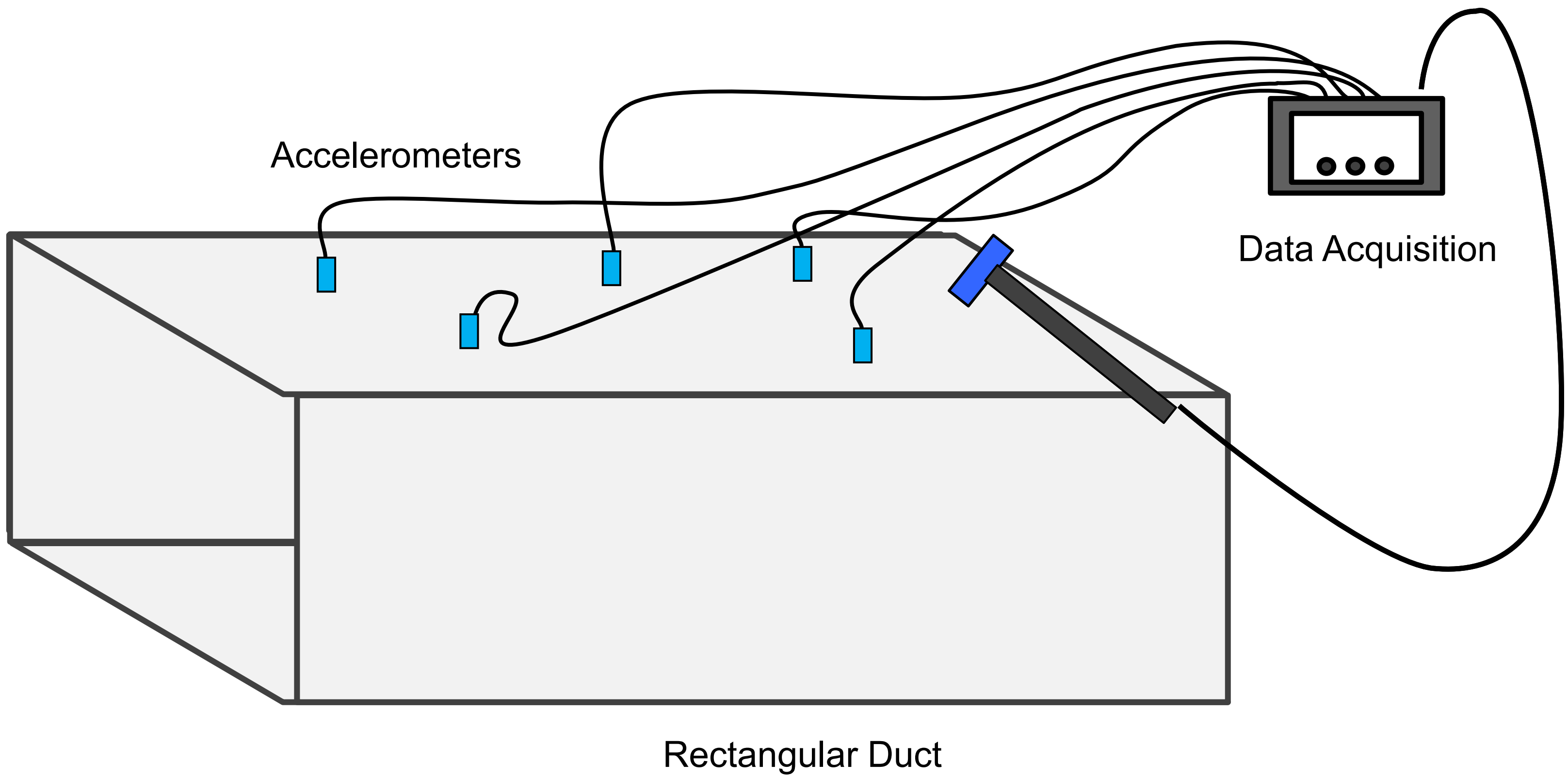


30 ft (9.15 m) Rectangular Duct



20 ft (6.10 m) Circular Duct

Damping Properties

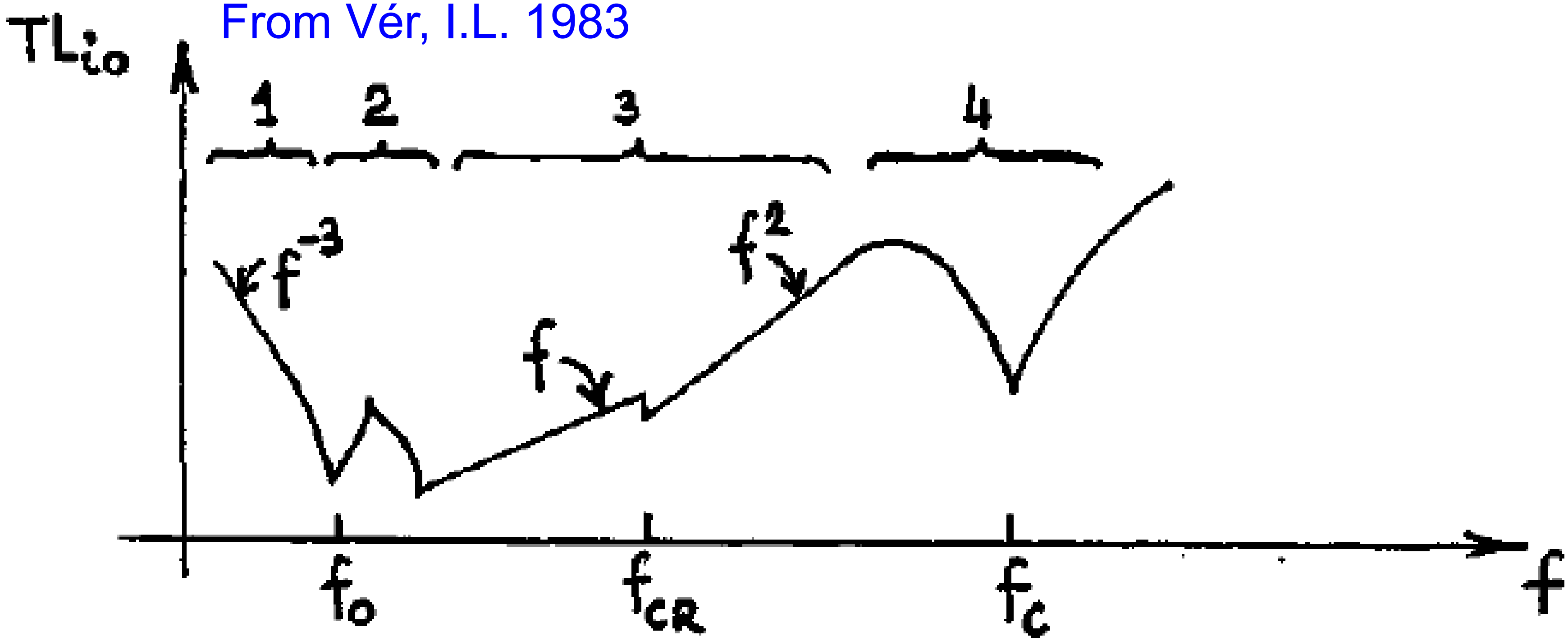


Measured Damping

Measured Damping Loss Factors						
	Circular	Rectangular				
Frequency (Hz)	10 in Diameter (25.4 cm)	10 in × 10 in (25.4 cm × 25.4 cm)	16 in × 16 in (40.6 cm × 40.6 cm)		32 in × 32 in (81 cm × 81 cm)	
	Unlined	Unlined	Unlined	Lined	Unlined	Lined
63	0.016	0.011	0.012	0.014	0.012	0.021
125	0.010	0.006	0.009	0.038	0.007	0.011
250	0.007	0.004	0.006	0.036	0.004	0.030
500	0.016	0.003	0.010	0.026	0.003	0.026
1000	0.008	0.003	0.007	0.022	0.003	0.022
2000	0.004	0.003	0.004	0.012	0.002	0.014
4000	0.002	0.004	0.004	0.007	0.002	0.009
8000	0.001	0.002	0.002	0.005	0.002	0.006

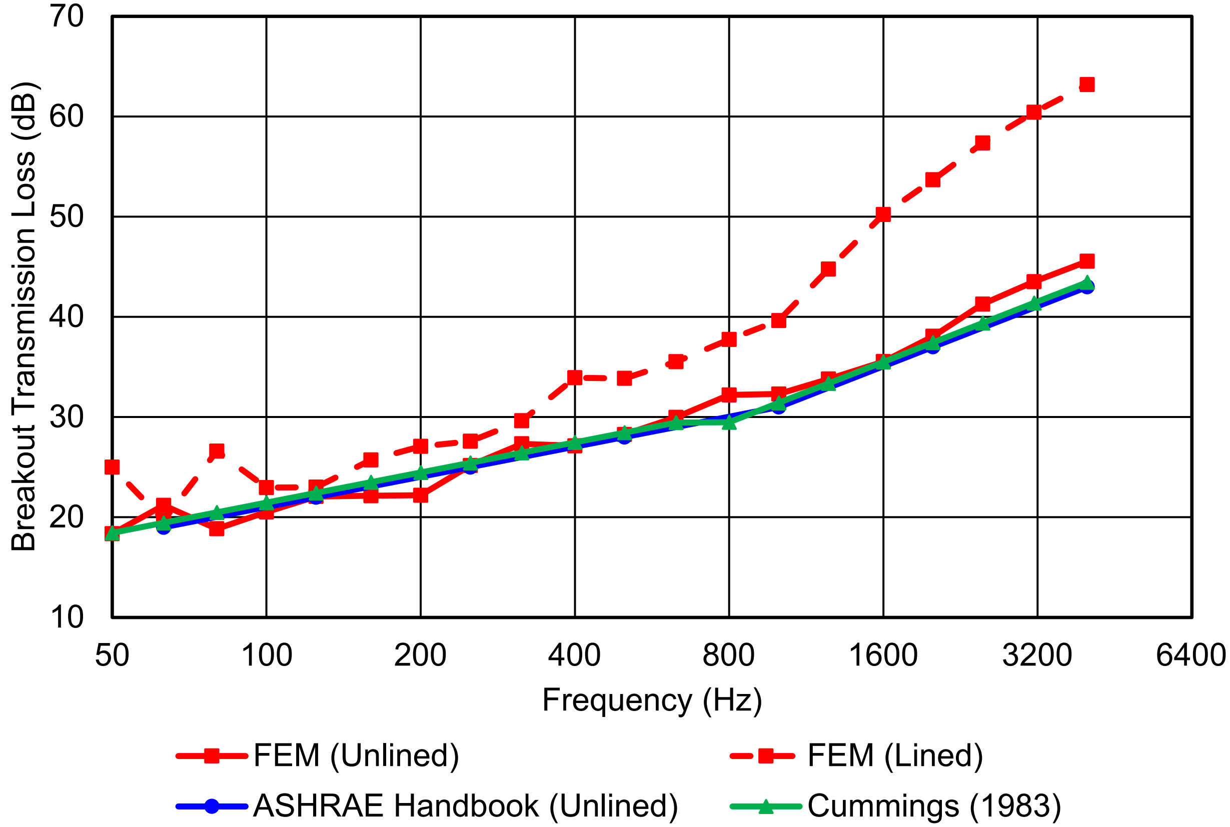
Rectangular Duct Breakout TL Curve

From Vér, I.L. 1983



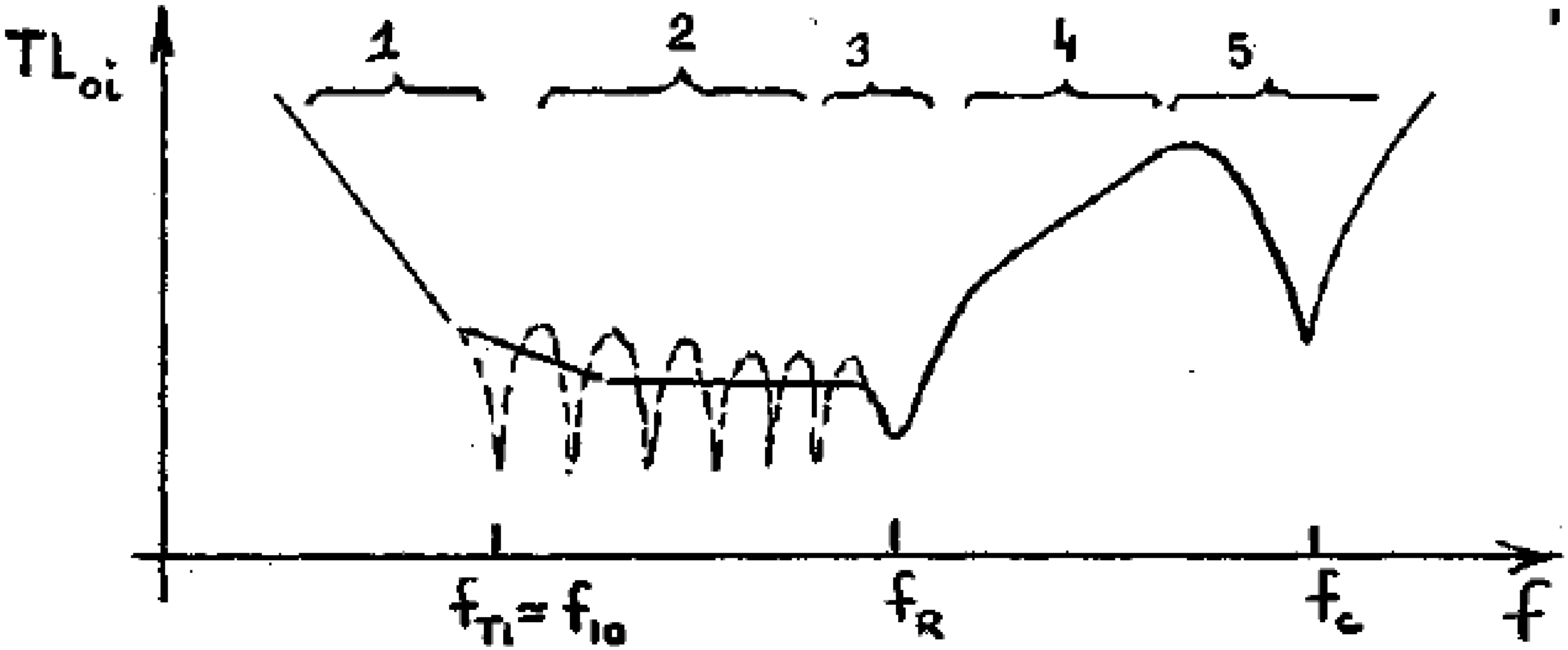
Breakout TL – Rectangular Duct

16 in x 48 in (0.4 m x 1.2 m) Rectangular Duct; 10 ft (3.1 m) Length
2 in (5 cm) Fiber Lining



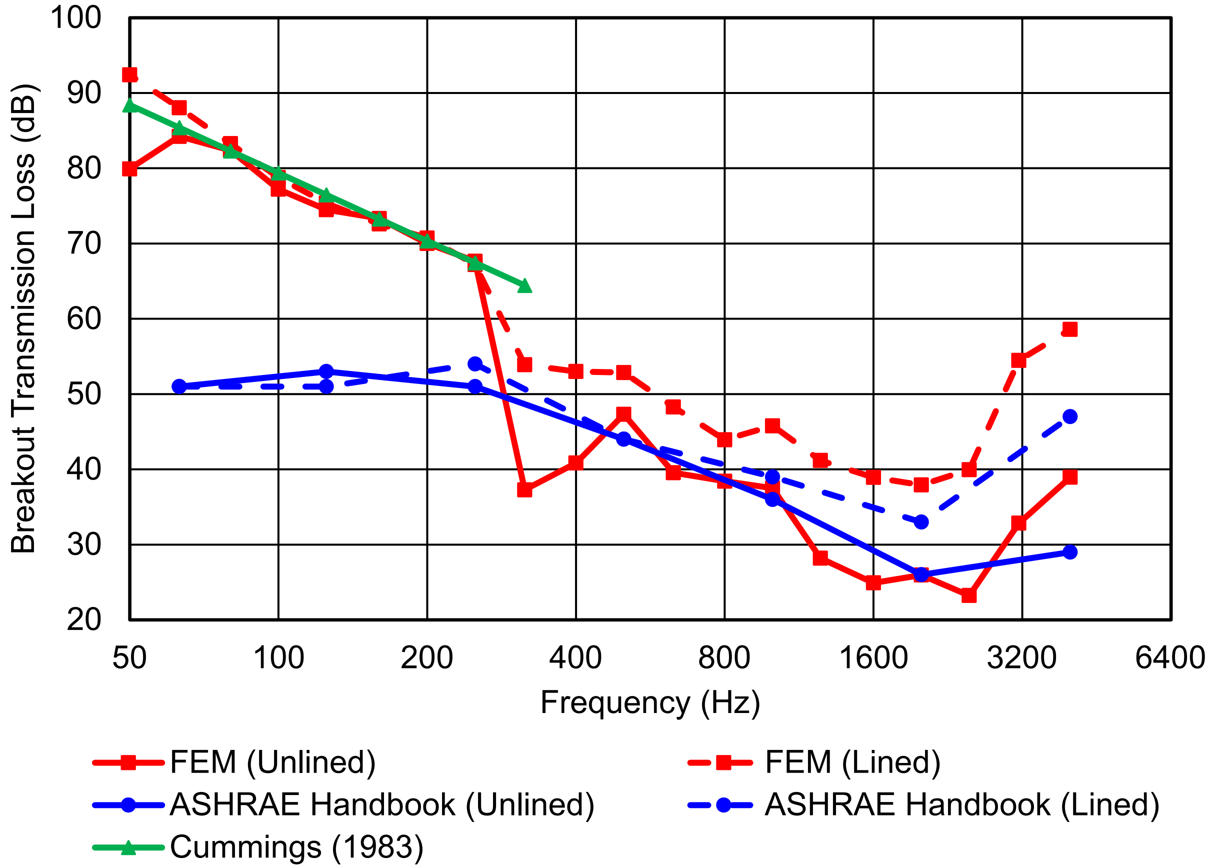
Circular Duct Breakout TL Curve

From Vér, I.L. 1983

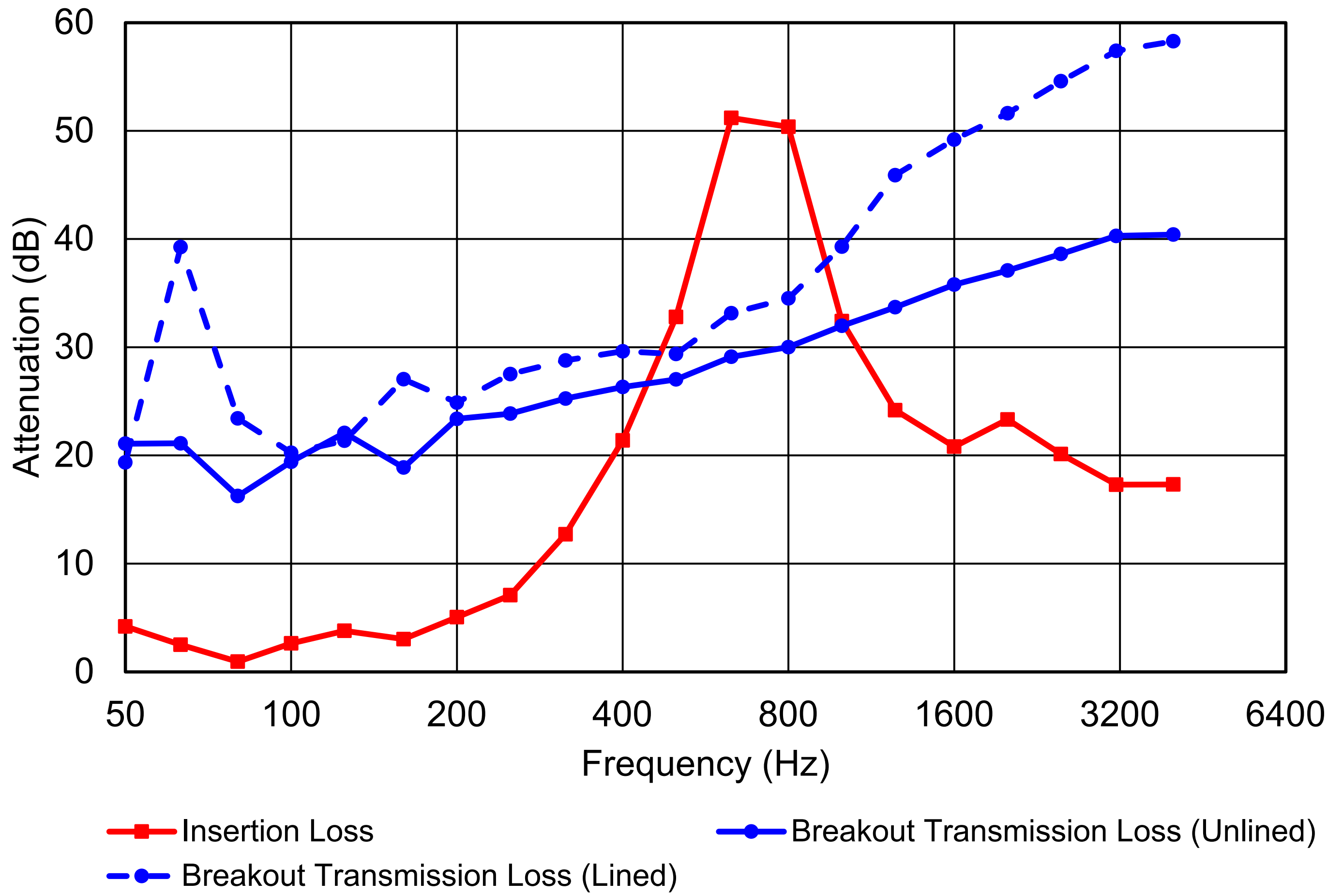


Breakout TL – Circular Duct

24 in (0.61 m) Diameter Duct; 20 ft (6.1 m) Length
2 in (5 cm) Fiber Lining



Importance of Breakout TL



Summary

- FEA approach qualified for predicting insertion loss of unlined and lined ducts, elbows, and plenums.
- FEA approach qualified for predicting breakout transmission loss.
- Approach can be used for design purposes and to fill in the gaps in the ASHRAE Handbook.

References

- K. Ruan and D. W. Herrin, “A Simulation Approach to Determine the Insertion and Transmission Losses of Unlined and Lined Ducts (RP-1529),” ASHRAE Transactions, Vol. 122, Part 1 (2016).
- K. Ruan and D. W. Herrin, “Using Simulation to Determine Elbow and Side Branch Attenuation and Duct Breakout Transmission Loss (RP-1529),” ASHRAE Transactions, Vol. 122, Part 1 (2016).
- D. W. Herrin and K. Ruan, “A Review of Prior ASHRAE Research Efforts to Characterize Noise Propagation in Ducts,” ASHRAE Transactions, Vol. 125, Part 1 (2019).