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DEFINITION OF AND RELATIONSHIP BETWEEN BREAKOUT AND BREAKIN SOUND TRANSMISSION LOSS OF PIPES AND DUCTS

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Introduction

This paper provides consistent definitions for the breakout and breakin sound transmission loss. On the basis of reciprocity it is shown that a definite relationship exists between the breakin and the breakout sound transmission loss. Reciprocity considerations also indicate that a peculiar behavior of the breakin sound transmission loss may exist.

Definition of Breakout Sound Transmission Loss

As illustrated in Fig. 1, it is appropriate to define the breakout sound transmission loss, TL_{io}, as [2]

$$TL_{io} \equiv 10 \log \frac{dW_{inc}(x)}{dW_{io}(x)} = 10 \log \frac{\frac{W_i(x)}{S} P\,dx}{dW_{io}(x)} \tag{1}$$

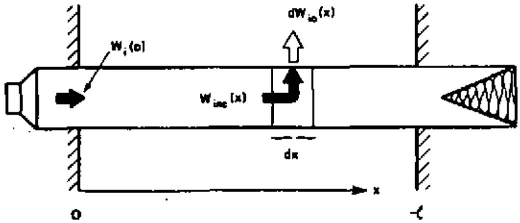

Fig. 1. Variables Involved in the Definition of the Breakout Sound Transmission Loss, TL_{io}.

where $W_i(x)$ is sound power in the duct at distance x from the source side end of the duct, P is the perimeter, S is the area of the duct cross section, and $dW_{io}(x)$ is the infinitesimal power escaping from the inside to the outside through sound transmission of length dx of the duct wall located at distance x. Based on the definition given in Eq. 1, the sound power radiated by the length ℓ of a duct, $W_{io}(\ell)$, is obtained as

$$W_{io}(\ell) = W_i(o)\,\frac{P\ell}{S}\,10^{-TL_{io}/10}\,C \quad \text{, where} \tag{2}$$

$$C = \frac{1 - e^{-(\tau+\beta)\ell}}{(\tau+\beta)\ell} \quad \text{, and} \tag{3}$$

$$\tau = \frac{P}{S}\,10^{-TL_{io}/10} \tag{4a}$$

$$\beta = \frac{\Delta L_1}{4.34} \tag{4b}$$

where ΔL_1 is the attenuation in dB per unit length inside the duct due to sound absorption by the porous lining. Equation 2 contains only measurable quantities and can be easily solved for TL_{io} by iteration.

Definition of Breakin Sound Transmission Loss

As illustrated in Fig. 2, the breakin sound transmission loss, TL_{oi}, is appropriately defined as [2]

$$TL_{oi} \equiv 10 \log \frac{dW_{inc}(x)}{dW_{oi}(x)} \tag{5}$$

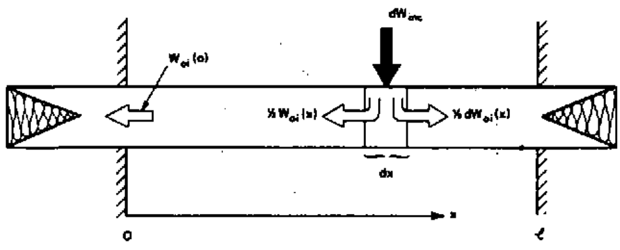

Fig. 2. Variables Involved in the Definition of Breakin Sound Transmission Loss, TL_{oi}.

Considering that the partial power $dW_{oi}(x)$ entering the duct through the small segment of length dx at location x exponentially decays before it reaches the reference end of the duct (located at x = 0) because of sound absorption in the lining and breakout, and summing the contributions of all incremental lengths dx from x = 0 to x = ℓ yields the sound power at the reference end of the duct, $W_{oi}(o)$,

$$W_{oi}(o) = \int_{o}^{\ell} \frac{1}{2}\, dW_{oi}(x)\; e^{-(\tau+\beta)x}\, dx = \frac{W_{inc}}{2}\, 10^{-TL_{oi}/10}\, C \qquad (6)$$

where W_{inc} is the sound power incident on the duct of length ℓ and C is that defined previously in Eqs. 3 and 4.

Relationship Between Breakout and Breakin Sound Transmission Loss

On the basis of a lengthy but straightforward reciprocity argument [1,2] it can be shown that the following relationship exists between the breakout sound transmission loss, TL_{io}, and the breakin sound transmission loss, TL_{oi},

$$TL_{oi} = TL_{io} - 10 \log \left\{4\gamma\left[1 + 0.64\, \frac{a}{b} \left(\frac{f_{cut}}{f}\right)^2\right]\right\} \qquad (7)$$

where f is the frequency, f_{cut} the cutoff frequency of the duct, a and b are the larger and smaller sides of the duct cross section $\gamma = 1$ below cutoff, and $\gamma = 0.5$ above cutoff.

Figure 3 shows the breakin sound transmission loss of a 12 in. x 12 in. 20 gauge unlined sheet metal duct as a function of frequency. The solid curve was obtained by directly measuring the breakin sound transmission loss; the open circles represent data points obtained by applying the reciprocity (emobodied in Eq. 7) to the measured breakout sound transmission loss. The agreement between directly measured and predicted TL_{oi} is very good above the cutoff frequency and satisfactory below the cutoff frequency.

The great importance of the reciprocity relationship embodied in Eq. 7 is that it makes it unnecessary to measure both the breakout and breakin sound transmission loss separately, because if one has been measured, the other can be predicted using Eq. 7.

Peculiarity of Breakin Sound Transmission

It is well known that if a dipole (consisting of two monopoles of equal strength but opposite phase spaced a short distance apart) is placed inside of a duct with its axis oriented perpendicular to the duct axis, no sound will propagate inside of the duct below the cut

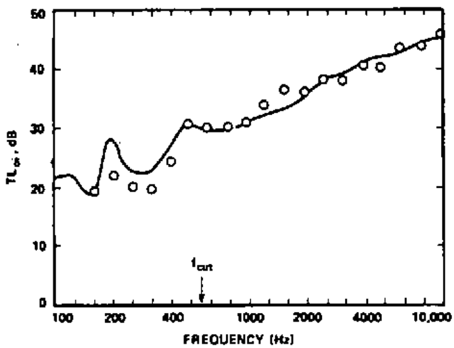

Fig. 3. Breakin Sound Transmission Loss of a 12 in. x 12 in. 20 gauge Unlined Sheet Metal Duct.

______ Measured by Ref. 3.
o o o o Predicted from Measured TL_{oi} using Eq. 7.

off frequency. Consequently, the duct far enough from the source location will not radiate sound. The reciprocity then implies that when a duct traverses a room where the sound field is excited by a dipole oriented perpendicular to the duct axis, the duct will not pick up any sound power from the room independently of the location of the dipole source in the room. At this time no experimental evidence is available to confirm or deny that his peculiar behavior indeed exists.

REFERENCES

[1] I.L. Vér, "Reciprocity as a Prediction and Diagnostic Tool in Reducing Transmission of Structureborne and Airborne Noise Into an Aircraft Fuselage," BBN Rept. 4985, Apr. 1982 (NASA Contract No. NAS1-16521).
[2] I.L. Vér, "Prediction of Sound Transmission Through Duct Walls; Breakout and Pickup, ASHRAE TRP-319 (BBN Rept. 5116, Jan. 1983).
[3] Courtesy of Mr. Allen Fry of Sound Attenuators Ltd., Colchester, England.