inter-noise 86
Cambridge, USA
1986 July 21-23

A METHOD TO ESTIMATE SOUND TRANSMISSION LOSSES IN AIR-DUCT NETWORK INCLUDING THE CONTRIBUTION OF REFLECTED-WAVES FROM DISCONTINUITIES

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1. INTRODUCTION

A method to predict low frequency natural attenuation in tree-type air-duct networks is investigated. To include the reflected wave's effects, an equivalent circuit method, which requires the characteristic reflection as well as transmission factor data of duct components, is introduced, against the conventional energy reducing method such as ASHRAE's[1] which requires only transmission coefficient data. The prediction error caused by the neglect of the contribution of reflected waves are also studied.

2. THE CALCULATION METHOD

Fig.1 shows an equivalent circuit model to calculate the natural attenuation of duct network. The term straight duct element represents the straight section which has enough length for the evanescent modes generated by the discontinuities to diminish. The term discontinuity component means the duct part whose all straight ducts connecting to the other discontinuity components satisfy the above diffinition on the straight duct element. Fig.

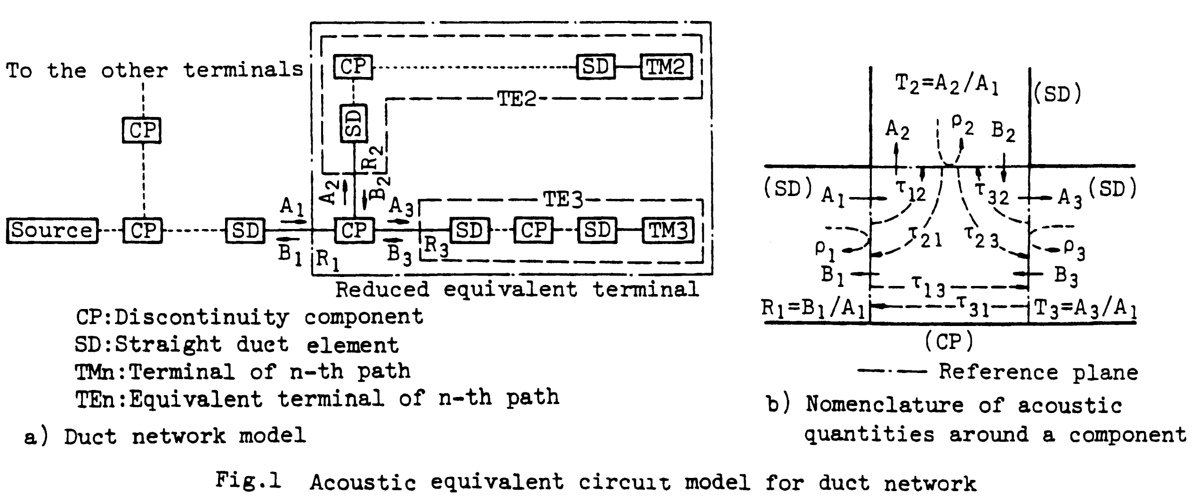


Fig.1 Acoustic equivalent circuit model for duct network

1b illustrates that the traveling waves and the characteristic factors defined at the input and output reference planes can be related to each other through the following linear expressions:

$$\begin{bmatrix} B_1 \\ A_2 \\ A_3 \end{bmatrix} = \begin{bmatrix} \rho_1 & \tau_{21} & \tau_{31} \\ \tau_{12} & \rho_2 & \tau_{32} \\ \tau_{13} & \tau_{23} & \rho_3 \end{bmatrix} \begin{bmatrix} A_1 \\ B_2 \\ B_3 \end{bmatrix} \qquad (1)$$

Where, a three-terminal pair discontinuity component are used for generality. A_m and B_m denotes the complex sound pressure amplitude of the traveling plane wave in positive and negative axial direction, respectively, at the m-th reference plane. τ_{mn} signifies the characteristic transmission factor for m-th plane input and n-th plane output, ρ_m the characteristic reflection factor for m-th reference plane. The reflection factors or equivalent reflection factors $R_2=B_2/A_2$, and $R_3=B_3/A_3$ having been given, the reflection factor $R_1=B_1/A_1$ as well as transmission factors $T_{12}=A_2/A_1$ and $T_{13}=A_3/A_1$ can be detarmined by this equations. Executing this from a terminal upward, transmission loss TL of every path can finally be determined.

3. THE CHARACTERISTIC FACTORS

Fig.2 shows a set of typical FEM and scale test models. Every transfer function of the sound pressure pair of the points in or between straight duct elements is observed. The pressures are provided by conducting a two-dimensional finit element method FEM and/or scale model test. Each complex sound pressure amplitude of the two traveling waves in the opposit directions in every straight duct being detected separately from those transfar

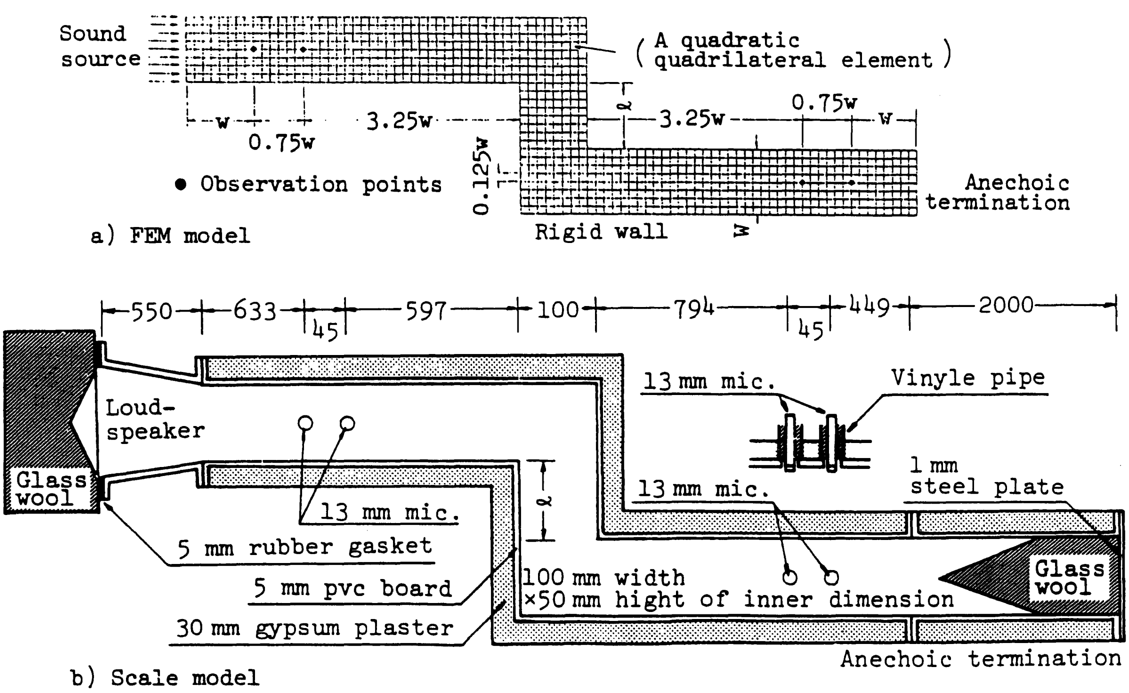
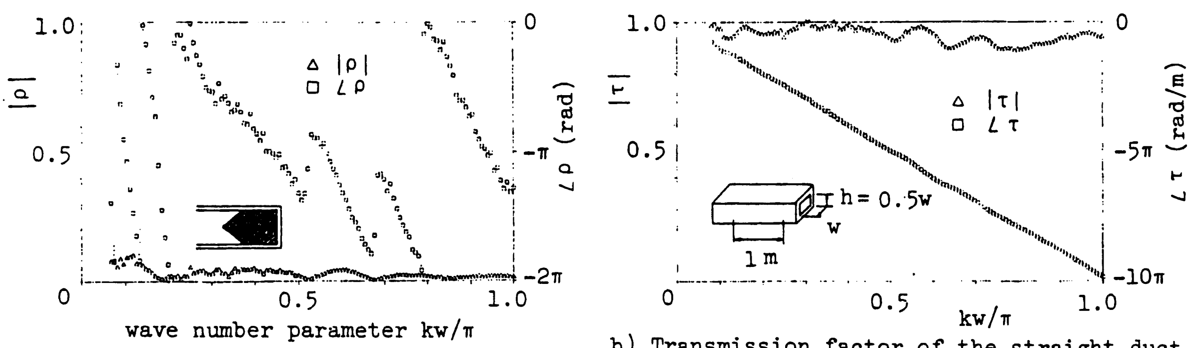


Fig.2 Typical models used for obtaining the acoustic factors of discontinuity components



a) Reflection factor ρ of the anechoic termination

b) Transmission factor of the straight duct per unit length, $\tau=e^{\gamma}e^{-jk}$

Fig.3 Properties of the anechoic termination and straight duct

fanctions[2], the characteristic factors of each component are obtained. Fig.3 shows measured characteristic factors of the anechoic termination and rectangular straight duct. Where, $k=2\pi\nu/c$ denotes wave number, ν frequency, c velocity of sound, γ attenuation constant (1/m). The characteristic factors at the reference planes are adjusted from those at the observation points by using the property of this straight duct section.

Fig.4-7 shows the results of the characteristic factors of several fundamental duct components. Where, w and l denotes the width and length of straight duct section, respectively. In ASHRAE, for a branth take-off, reflection coefficients $|\rho|^2$ are to be negregible, and transmission coefficients $|\tau|^2$ are to be equal to the sectional aria ratio of the branch to all of the branches. The results obtained by FEM for loss free cases may be the most reliable of the methods, since those by FEM agree well with those by thoretical and measured.

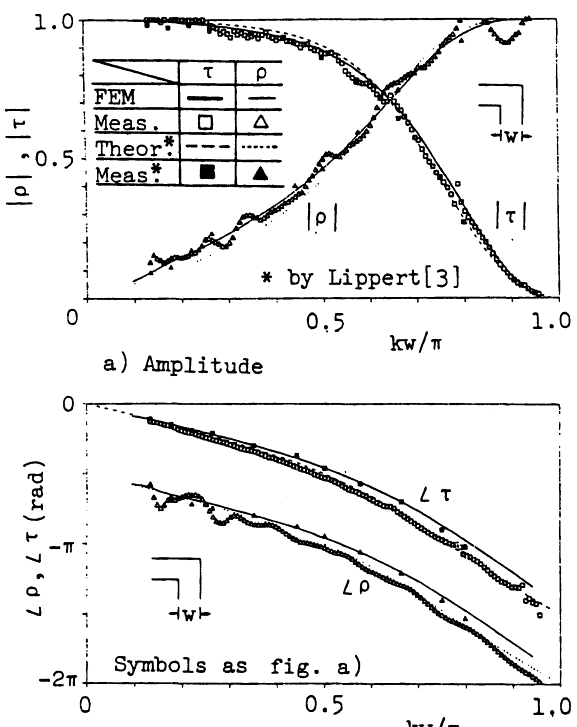


Fig.4 Characteristic reflection factor ρ and transmission factor τ of the rectangular mitered elbow

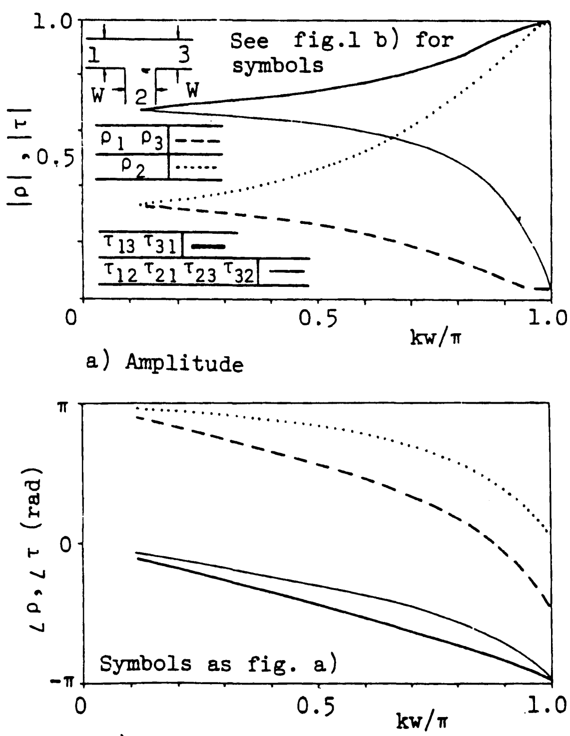
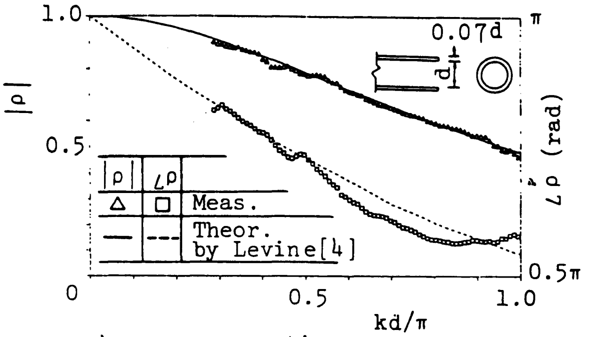
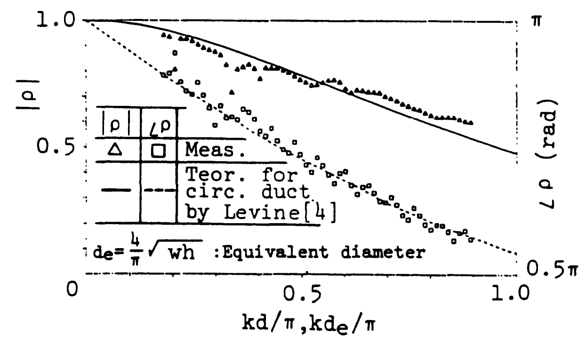


Fig.5 Characteristic reflection factor ρ and transmission factor τ of the rectangular T-shaped take-off

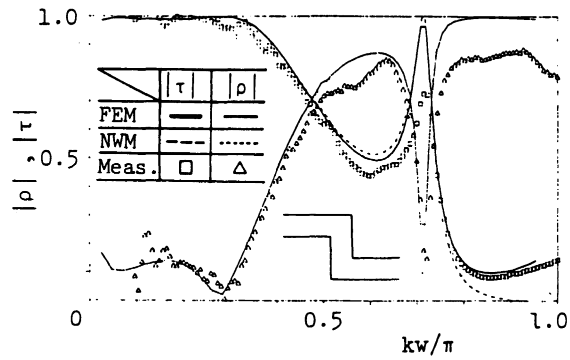


a) Circular section

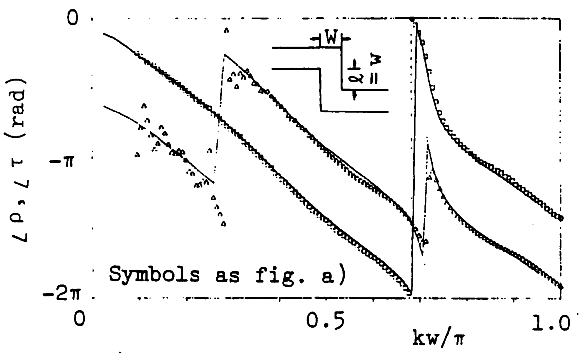


b) Rectangular duct with cross section w×h

Fig.6 Characteristic reflection factor ρ of an open end



a) Amplitude



b) Phase

Fig.7 Characteristic reflection factor ρ and transmission factor τ of the double elbow with ℓ = w

4. VALIDITY OF THE METHOD

Fig.8 a-d show the calculated transmission losses for the double elbows. Where, FEM denotes the result by using directly FEM for the double elbow component, EGM and NWM denotes the energy reducing method and equivalent circuit network method respectively, in which the same characteristic factors by FEM of the foregoing paragraph are used. The upper limit of kw/π up to which the TLs predicted by NWM agree well with those by FEM approaches unity, as l/w increases. This implies the validity of the calculation processes by NWM cannot predict such almost perfect penetration at many frequencies.

Fig.9 reveals the sound pressure and net intensity vector distributions for three frequencies around kw/π=1. At kw/π=0.882 for l/w=2, the assumption for eq.(1) lacks the effectivity,since there is not any sectional part where only traveling wave in axis direction is uniformly exist, Desireted frequency range kw/π being up to 0.9 for prediction by NWM, the minimum straight duct element length l/w must at least be 4, at deviding the network into the components.

5. DIFFERENCE IN PREDICTED VALUES BETWEEN THE METHODS

Fig.10 illastrates one of duct networks by which the followings are discussed. Fig.11a shows the spectral TLs for the 1st path, i. e. between the source and the output of 1st terminal. Where, TL_E and TL_N signifies the TL by EGM and NWM respectively. Fig.11b shows 1/1 octave band TLs calculated by using those spec-

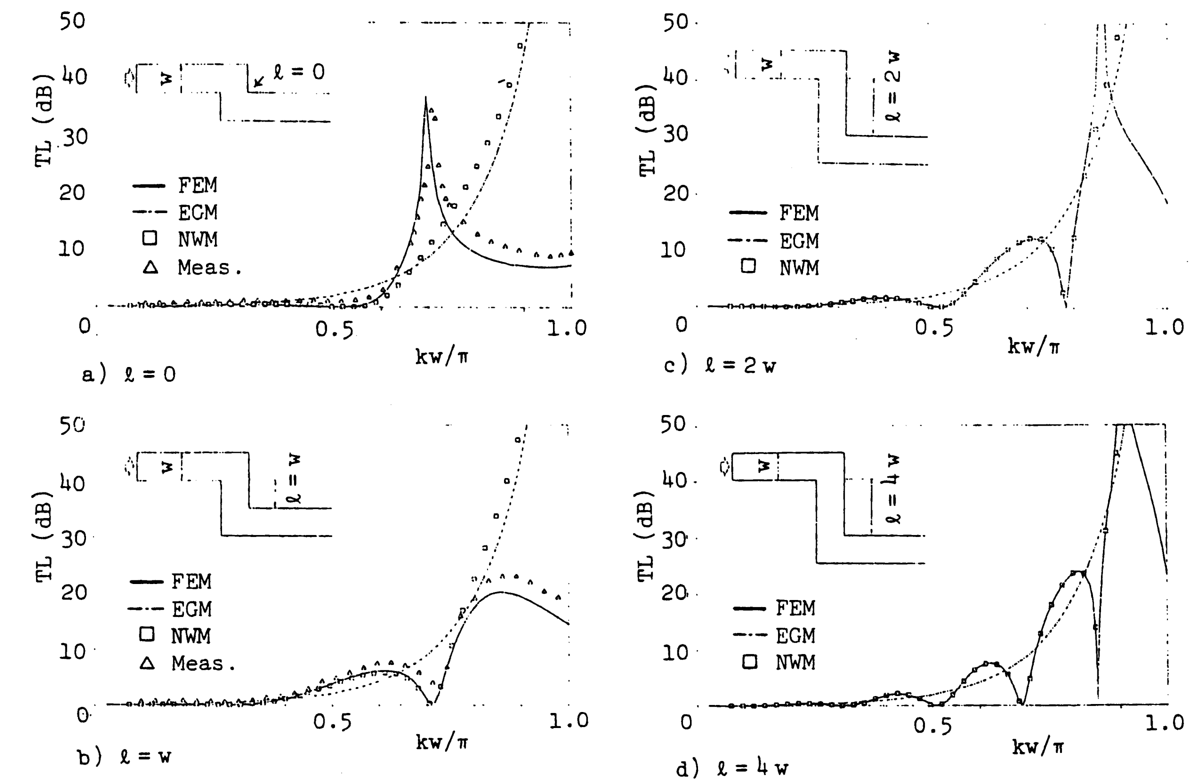


Fig.8 Transmission loss TL of the double elbows

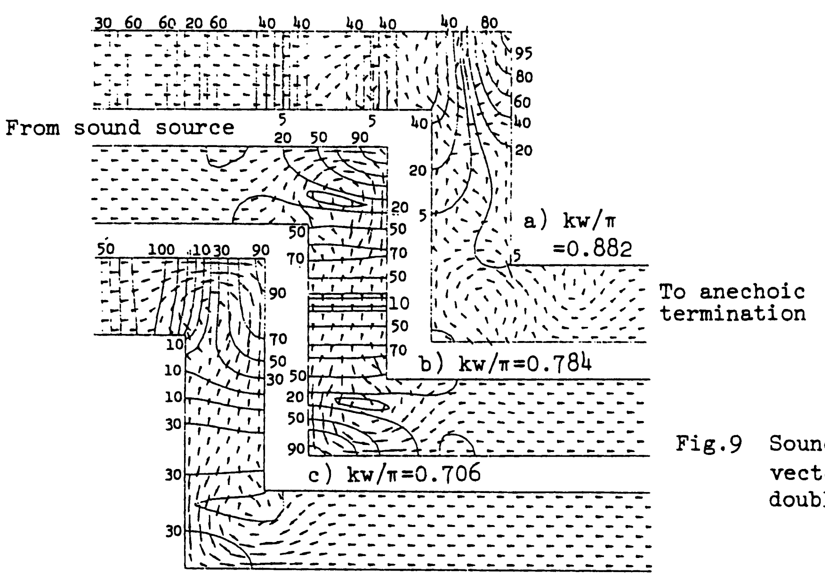
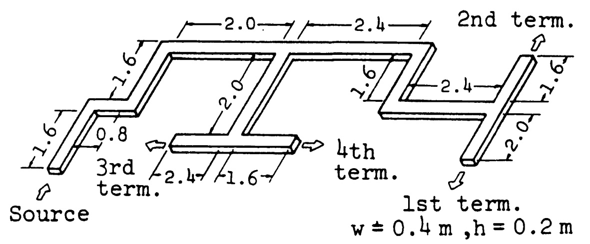


Fig.9 Sound pressure and net intensity vector distribution around the double elbow with ℓ= 2w

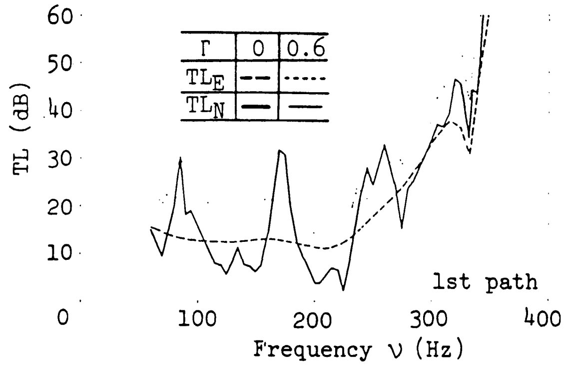
tral TLs for white noise input. Where, TL_A denotes TL by the energy reducing method by ASHRAE's simplified transmission coefficient data. $\Gamma=\gamma\times 20\log_{10}e$, (dB/m) denotes the attenuation of straight duct, which is dealt to be between 0.3 and 0.6 dB/m in ASHRAE. The difference in TL_E and TL_N still remains not small for this extent of natural attenuation.

Fig.12 represents prediction error in TL by those energy reducing methods. Where, $\Delta TL_E=TL_E-TL_N$ implies the TL prediction error caused by the neglect of reflected wave contribution, and $\Delta TL_A=TL_A-TL_N$ that caused by simplified ASHRAE's data as well as ΔTL_E. For any path of this network, ΔTL_E is positive, i. e. of



All dimensions in meters

Fig.10 A tree type duct network



a) Spectrum

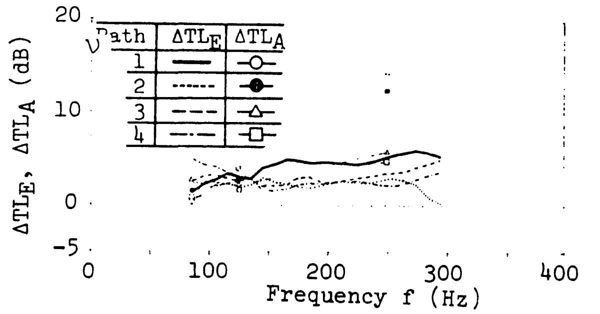
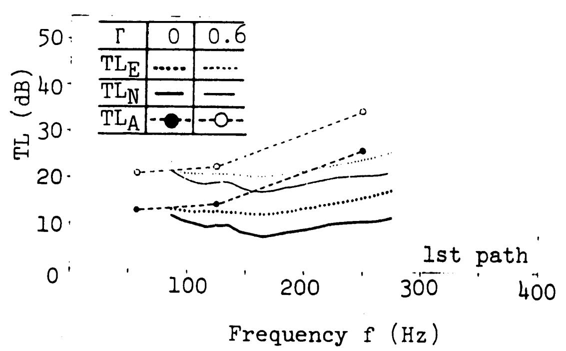


Fig.12 Prediction error in TL of the energy reducing method (1/1 octave band, $\Gamma = 0.6$ dB/m)



b) 1/1 octave band

Fig.11 Difference in transmission loss TL between calculation methods

prediction error toward risky side, since the energy at the penetrating frequency has a dominant contribution to the 1/1 octave band TL. The extreme case is that of the 1st path. Preparing for the worst, the energy reducing method may frequently give overestimation in TL prediction by about 5 dB,and that using ASHRAE's simplified data by over 10 dB. This result is also true in the other duct networks studied.

6. SUMMARY

It is suggested that the usual energy reducing method neglecting reflected wave effect and ASHRAE's simplified method for natural attenuation prediction of duct networks may frequently give overestimation in octave-band transmission loss approximately 5 dB and over 10 dB, respectively. In contrast to this, the equivalent circuit method is clarified to be effective, in which characteristic reflection as well as transmission factors for several fundamental duct components are newly provided and applied.

7.REFERENCES

[1]ASHRAE handbook, System vol.,Chap. 35(1980) .
[2]M.Terao & H.Sekine, AIJ Trans. Environ. Eng. Arch.,6,25(1984).
[3]W.K.R. Lippert, Acustica, 4, 313(1954) .
[4]H. Levine & J. Schwinger, Physical Review, 73, 383(1948)