中華民國音響學會
第四屆學術研討會論文集

中華民國音響學會
行政院環境保護署 合辦

中華民國八十年十一月二十二日

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Comparison of Sound Properties in Various Spaces for a Sound Environment Design

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Takako OTSUKA (Wakabayashi Acoustic Design)

1. Introduction

A sound environment design must be implemented after all characteristics of the field where it is to be implemented are fully understood. This is because no sound environment design has a type which can be applied to any kind of field. In such a situation, it is considered to be an extremely effective and important condition for a sound environment design that we should fully understand the present aspects concerning sound in various areas in different countries. Therefore, we investigated and analyzed sound in various districts in many countries, and further classified and compared the results of our investigations according to several applications. This report describes the result of comparison of the properties of sound in Japan and in Southeast Asia (including Taiwan and Korea).

2. Methods of Measurement and Analysis

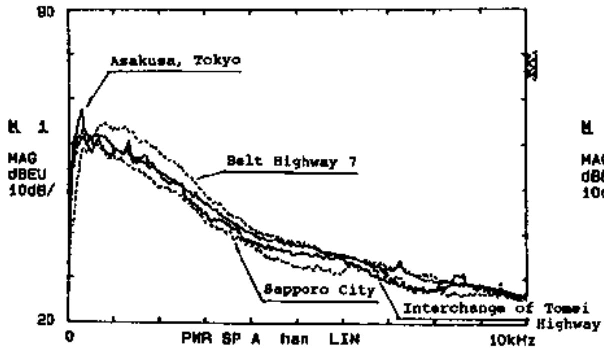
For the measurement of sound properties, we not only collected sounds but attached importance to visual factors of the sound environments. For the latter purpose we used a still camera and DAT (Sony) in earlier stages. In recent measurements, a high-band 8 mm video camera and DAT were jointly used, in addition to the still camera, to record images and sounds simultaneously. The following places or sound environments were selected to collect sound data:

(1) Trunk road in a town area
(2) Narrow street in a town area
(3) Railway station which is a public transportation facility
(4) Public square
(5) Hour ring and voice of street venders

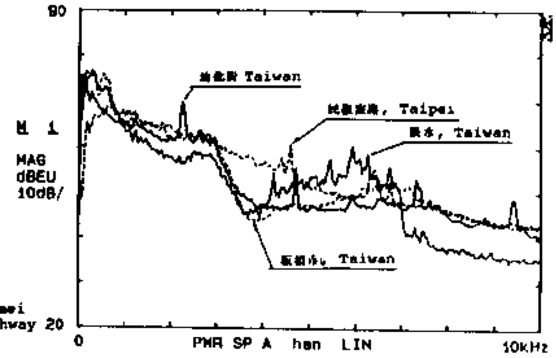
When collecting data in soundspaces (1) through (4) above, we took care to choose proper locations where almost same sound environments would be kept throughout the year. With respect to (5), we selected such measurement sites that were convenient for data collection. Furthermore, for all these 5 kinds of sound environments we attempted to measure at appropriate distances which would not give unnaturalness to the sense of hearing. The method of sound analysis was as follows. First, L_{eq} was measured for certain periods (1 to 5 minutes) with a sound level meter while reproducing the recorded sounds. Next, sound spectrum was analyzed three-dimensionally (Ono Sokki CF360) to figure out the sound properties.

3. Measurement Results

The results of our measurements are shown below.

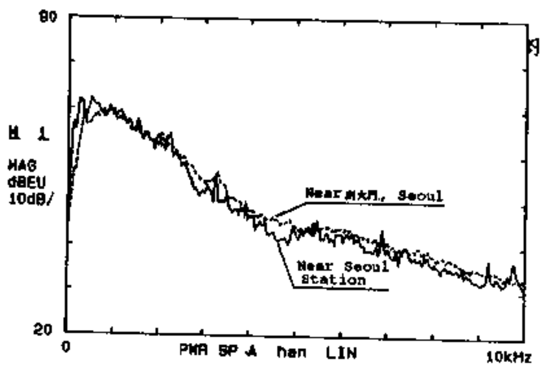


a) Japan

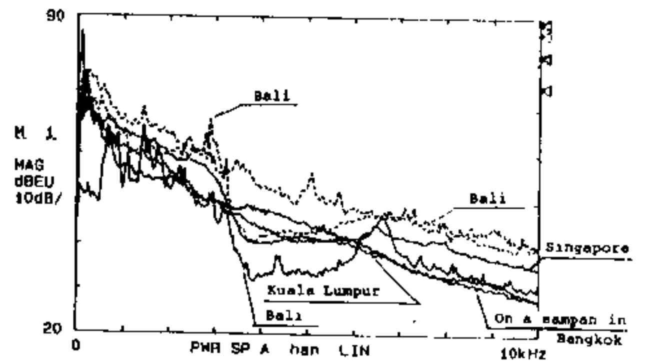


b) Taiwan

Figure 1 Trunk Roads

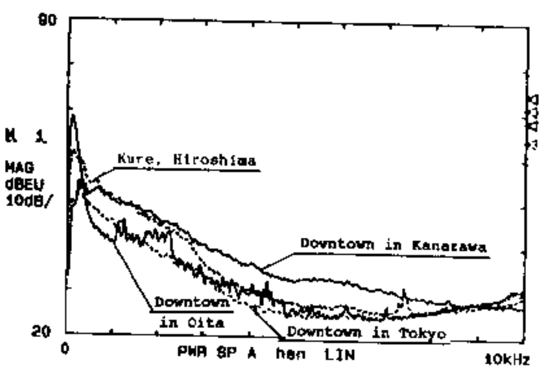


c) South Korea

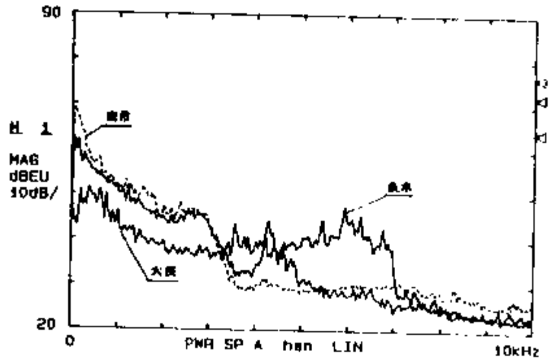


d) Southeast Asia

Figure 1 Trunk Roads

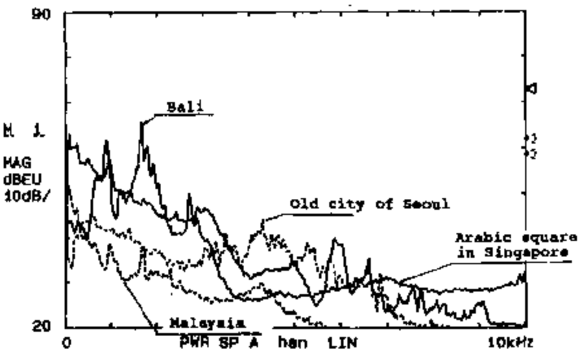


a) Japan



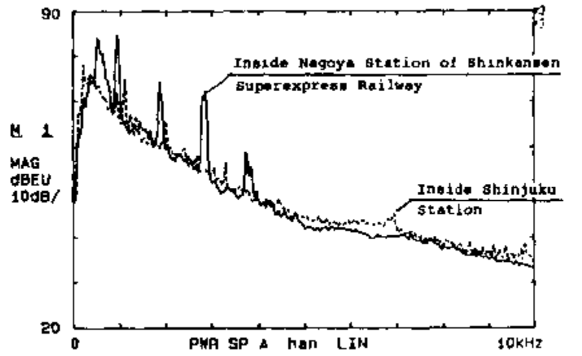
b) Taiwan

Figure 2 Downtown Streets



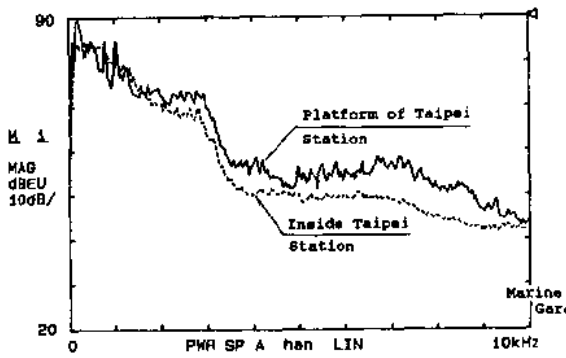
c) Southeast Asia

Figure 2 Downtown Streets



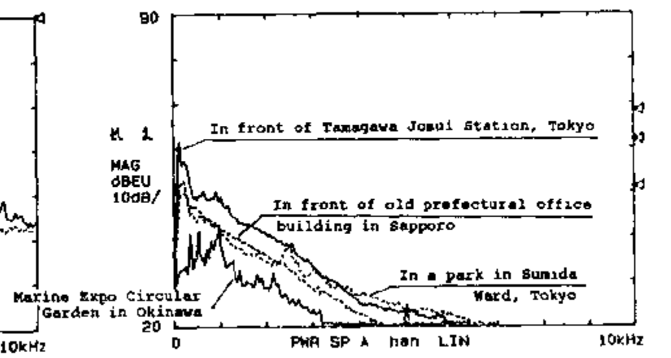
a) Japan

Figure 3 Stations



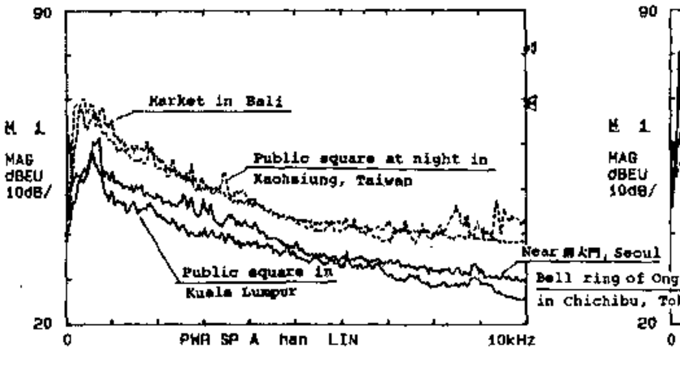
b) Taiwan

Figure 3 Stations



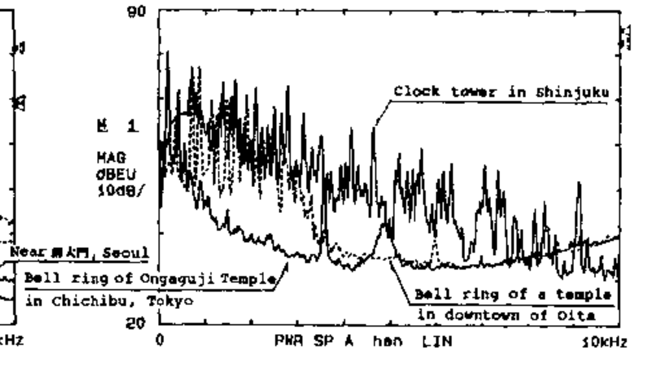
a) Japan

Figure 4 Public Squares



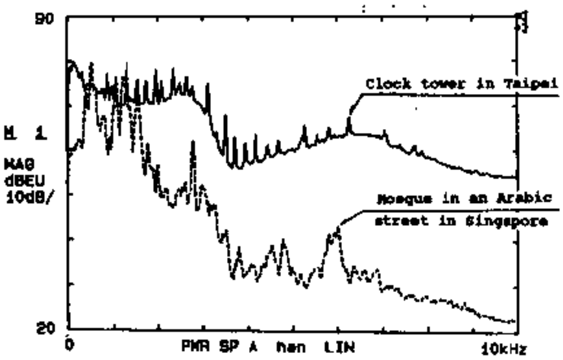
b) Southeast Asia

Figure 4 Public Squares



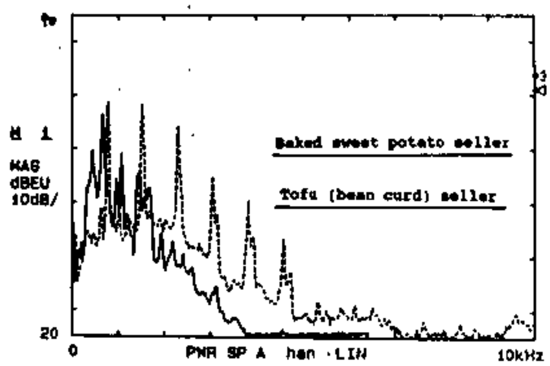
a) Japan

Figure 5 Hour rings



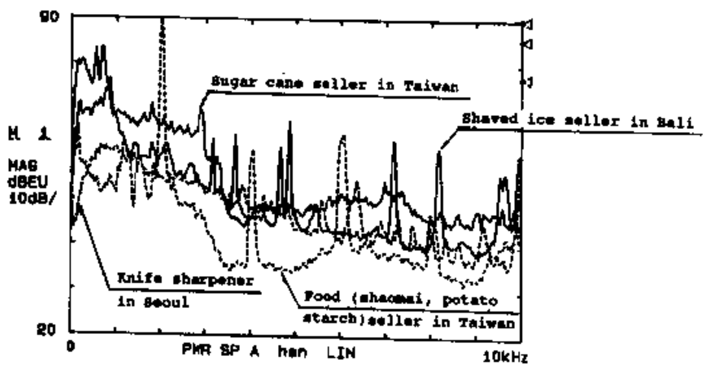
b) Southeast Asia

Figure 5 Hour rings



a) Japan

Figure 6 Voice of Street Venders



b) Southeast Asia

Figure 6 Voice of Street Venders

4. Discussion on the Results of Analysis

First, from Figures 1 and 2, it is noted that there is a certain difference in road traffic sound properties in Japan, Southeast Asia and South Korea. The difference is that while the traffic noise observed in Japan shows spectra close to the 1/f pattern, the noise level in other countries first decreases up to around 3 to 5 kHz, then increases again at higher frequencies. This would indicate that the noise in those countries contains more high-frequency components, giving a noisy impression to the ears.
With respect to the road traffic, the rate of vehicles with small displacement is high in Southeast Asia and Taiwan. This is considered to be another reason that adds to the noisiness of the traffic. On the other hand, the configuration of vehicles in South Korea is very close to that of Japan. The sound spectra also show similar characteristics as Japan. It is understood from these facts that the difference in the performance and construction of vehicles results in an obvious difference in sound properties.

Comparison between trunk roads and narrow streets indicates lower noise levels in the latter soundspace. Presumably, one of the reasons for this tendency is that the running speed of vehicles is limited due to the narrow and somewhat complicated construction. As in the case of the trunk roads, the noise level on narrow streets of Taiwan decreases toward 3 to 4 kHz, then increases again at higher frequencies.

Next, as clearly seen in Figure 3, the sound spectra obtained in a railway station in Taiwan show reduced noise levels around 3 to 5 kHz followed by higher noise levels at the higher frequency range. The measurement in Japan shows random peaks at low frequencies. Although the spectra have different patterns in the two countries, the stations in both countries give a noisy impression with their respective sound properties.
In Japan, a public square usually means a place of relaxation like a park. Probably based on this concept, public squares in Japan are characterized by low noise levels, as shown in Figure 4. On the contrary, a typical public square in Southeast Asia is a marketplace closely related to the people's living, where the general public come for shopping. The noise level in such a place is not so low at all, but the spectra resemble the 1/f pattern sloping down gradually. Probably for this reason, one can feel liveliness, instead of noisiness, in the latter type of public square.

Various spectrum patterns are observed in hour rings as shown in Figure 5. Here again, the measurements in Southeast Asia show the spectrum pattern once falling and rising again.
The voice of street sellers, shown in Figure 6, can rarely be heard in Japan today, but in Southeast Asia it can still be heard everywhere. In most cases, their voice comes through a loudspeaker in Japan. Contrarily, the use of a loudspeaker is not common in Southeast Asia. Perhaps, this is the reason why the voice of Southeast Asian street sellers sounds gentle to the ears. The voice of street sellers can be understood as a culture backed by the history of each country and each region. Accordingly, there is a variety of spectra in street sellers' voice. The loudspeaker may have such effects that make various spectrum patterns to resemble one another.

5. Conclusion

As examined in the preceding paragraphs, there is a variety of sound properties in different areas and in individual soundspaces. Major factors that cause this variety are considered to be the differences in the design and materials of buildings, automobiles, or other technical differences, climate and customs. Under such circumstances, it is most important that sound environment design is made to suit each individual soundspace. For new city or town planning, we should not take such a process that would simply apply an already known pattern, but we should determine a design based on a full understanding of the present status of each individual case. In this respect, it would be required to try various methods of reducing the current noise levels and put appropriate methods in practice. On the other hand, should the need arise to make something that would emit any noise, it should be developed with utmost care. In this paper, we compared the environmental sound properties measured in Japan, Southeast Asia, Taiwan and South Korea. Next, we would like to examine the sound environments in Europe and the United States in comparison with Japan.

英文摘要

Duct acoustics has been applied to analyse the acoustic energy loss in two and four sides duct lining by two different materials. One is honyecomb & perforated absorption material and the other is fiber type absorption material. Different duct scale parameters such as aspect ratio, length, and thickness, impedence parameters such as specific flow resistivity, static shape factor, tortuosity, porosity, characteristic frequency of perforated metal sheet and Mach number are studied. Their effects to acoustic energy loss are computed by numerical method.

The results show that the acoustic energy loss will be increased as specific flow resistivity or thickness decreases, or the charcteristic frequency of perforated metal sheet increases in honyecomb type absorption material. It will be increased as specific flow resistivity or tortuosity decreases, or static shape factor, porosity or thickness increases in fiber type absorption material. The senstivity analysis shows that these parameters have the following order of importance : namely porosity, tortuosity, static shape factor and specific flow resistivity. Acoustic energy loss increases as negetive Mach number increases and positive Mach number decreases for both types of materials. The two & four sides lining will have about 3dB & 12dB difference in acoustic energy loss in fiber and honeycomb absorption material respectivly.

中文摘要

利用管路聲學解析導管內被覆兩面或四面蜂巢及打孔金屬板吸音材、纖維吸音材之能量損失，並運用阮奇庫達法(Runge-Kutta Method)及修正牛頓拉普森法(Modified Newton-Raphson Method)來模擬不同馬赫數、導管長度、高度、吸音材厚度、不同阻抗如比流阻、彎曲度、多孔度等參數變化對聲能損失(Acoustic Energy Loss)之影響。結果顯示導管被覆蜂巢及打孔金屬板吸音材之聲能損失隨比流阻、厚度之減少及特徵頻率之增加而增加。導管被覆纖維吸音材時，隨比流阻、彎曲度之減少及多孔度、靜形狀因子、厚度之增加而增加。靈敏度依序為多孔度、彎曲度、靜形狀因子、比流阻。且聲能損失於兩種情況下均隨正馬赫數之增加而遞減，隨負馬赫數之增加而增加。聲能損失隨長度之增加及高度之減少而增加。蜂巢型及纖維型吸音材於兩面及四面被覆下，聲能損失相差分別約為十二分貝及三分貝。

A Numerical Simulation for The Energy Losses of Duct Lining

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*: Chung Shan Institute of Science and Technology
**: Professor of Institute of Engineering Science
National Cheng Kung University

Abstract

Duct acoustics has been applied to analyze the acoustic energy loss in two and four-side duct lining by two different materials. One is honeycomb and perforated absorption material and the other is fiber type absorption material. Duct scale parameters such as aspect ratio, length and thickness, and impedence parameters such as specific flow resistivity, static shape factor, tortuosity, porosity, characteristic frequency of perforated metal sheet and Mach number are studied. Their effects to the acoustic energy loss are computed by numerical method.

The results show that the acoustic energy loss increases as the specific flow resistivity or thickness decreases, or the charcteristic frequency of perforated metal sheet increases in honeycomb type absorption material.It increases as the specific flow resistivity or tortuosity decreases, or static shape factor, porosity, thickness increases in fiber type absorption material. The senstivity analysis shows thet these parameters have the following order of importance : namely, porosity, tortuosity, static shape factor and specific flow resistivity. Acoustic energy loss increasesas negative Mach No. increases and positive Mach No. decreases for both types of materials. The two- and four-side lining will have about 3dB and 12dB difference in the acoustic energy loss in fiber and honeycomb absorption material respectivly.

1. Introduction

Duct Acouctics may he applied to analyze typical noise pollution problems around our environments,such as air-conditioning fans, engines, subways and the transportation noise of Rapid Transient System , etc. It is commonly understood that by inserting an expansion chamber,a cavity resonatoror,active control speakers, one may reduce the low frequency duct noise. And wrapping or lining absorption materials outside or inside of a duct, or inserting silencers between source and receiver can reduce high frequency noises. The acoustic energy loss (noise reduction) prediction of duct-lining in frequency domain and relevent parameters study is our interesting. The basic model of two and four duct-lining in Fig. 1 will be discussed in this paper.

Kinsler [1] has discussed the phenomena of sound propagation in unlined duct without mean flow. Benzakein et al. [2] analyzed the lined duct without mean flow also. Meyer et al.[3] measured the acoustic energy losses of duct-lining of perforated metal and rockwool absorption material in different Mach Number mean flows. Also at the same conditions Haley [4] investigated the duct-lining of perforated metal and honeycomb absorption material , And studied the acoustic energy loss in different specific flow resistivity, material thickness, duct aspect ratio & the characteristic frequency of perforated metal sheet systematically. Ko [5] derived the acoustic energy loss of duct lining using tha same model as Haley [4] and got results in good agreement with experimental data. In addition, Manjal [6] took of Attenborough model fiber type absorption material and analyzed the square duct-lining in different Mach No. mean flows & thicknesses.

This study follows Ko's two-lining duct data to check the computer program first. Then applies this program to duct with four-lining condition and extends to more parameters. Thus it is a more detailed study than the above authors.

2. Mathmatical Formulation

To derive the wave propagation equation along the duct lining, axisymmetric and anti-axisymmetric eigen - equations are the most important work in the formulation. Basic assumptions of this problem are lining of the local reaction absorption material throughout the rigid duct wall, no standing wave, no shear flow and heat transfer in the duct, duct length is infinite and no reflection wave exists in the duct. Furthemore, input acoustic waves are random signal with the same sound amplidute for each frequency. The nondimensional wave-enquations & eigen-enquations are listing by (1)(2)(3) for two-lining case and (4)--(9) for the four-lining condition.

- Case of two-lining duct:

$$i\pi f^* Y(1 - Mk^*_{mn}/k^*)^2 = k^*_m \tan(k^*_m) \quad \text{--- (1)}$$

$$i\pi f^* Y(1 - Mk^*_{mn}/k^*)^2 = -k^*_m \cot(k^*_m) \quad \text{--- (2)}$$

$$k^*_{mn}/k^* = \{-M + [1 - (1 - M^2)((k^*_m/k^*)^2 + (k^*_n/k^*)^2)]^{0.5}\} / (1 - M^2) \quad \text{--- (3)}$$

- Case of four-lining duct:

-- For x-direction lining:

$$\begin{cases} i\pi f^{*} Y_{x} (1 - M k^{*}_{mn}/k^{*})^{2} = k^{*}_{n} \tan(k^{*}_{n} B/A) & (4) \\ i\pi f^{*} Y_{x} (1 - M k^{*}_{mn}/k^{*})^{2} = -k^{*}_{n} \cot(k^{*}_{n} B/A) & (5) \\ k^{*}_{mn}/k^{*} = \{-M + [1 - (1 - M^{2})((k^{*}_{n}/k^{*})^{2} + (k^{*}_{m}/k^{*})^{2})]^{0.5}\} / (1 - M^{2}) & (6) \end{cases}$$

-- For Y-direction lining:

$$\begin{cases} i\pi f^{*} Y_{y} (1 - M k^{*}_{mn}/k^{*})^{2} = k^{*}_{m} \tan(k^{*}_{m}) & (7) \\ i\pi f^{*} Y_{y} (1 - M k^{*}_{mn}/k^{*})^{2} = -k^{*}_{m} \cot(k^{*}_{m}) & (8) \\ k^{*}_{mn}/k^{*} = \{-M + [1 - (1 - M^{2})((k^{*}_{n}/k^{*})^{2} + (k^{*}_{n}/k^{*})^{2})]^{0.5}\} / (1 - M^{2}) & (9) \end{cases}$$

These equations are solved numerically by Runge-Kutta method and Modified Newton - Raphson method to obtain the acoustic energy losses.

2.1 Impedence Model of Absorption Material:

The impedence of absorption material in equations (1) -- (9) must be known beforehand when solving for the complex wave numbers. So it is necessary to setup a suitable impedence model first to simulate the absorption effects. Rayleigh [7] has described the propagation acoustic wave in a tube & the dissipation of acouctic energy to thermal energy due to the frictional and viscous effects by capillary model. Beranek [8] considered the impedence dependency on the effects of gas density & compressiblity, specific flow resistivity and structure factor. Delany and Bazley [9], and Qunli [10] collected the experimental data of fiber and foam type absorption material respectively to obtain semi-imperical formula. Both of them are functions of specific flow resistivity and do not fit well in the low frequency range. Attenborough [11] has used a phenomenological and microstructural point view to analyse the impedence of rigid or flexible fiber type material in parallel, stacked and random directions by scattering theorem. The impedence is function of porosity, tortuosity, specific flow resistivity, and static & dynamic shape factor . This study uses impedence of honeycomb material by Ko, fiber type material by Attentborough, and multilayer impedence by Duun and Davern [12] as following:

- Impedence of honeycomb material :

$$Z = R*[1.0 + i*(f/f_{0})] - i*\cot(kd)*\rho c$$

- Impedence of fiber type material :

$$Z = Z_{c} * \coth(k_{b} d)$$

where $Z_{c} = w*\rho_{b}/k_{b}$

$$\rho_{b} = (Q^{2}/\Omega)*\rho_{p}$$

$$\rho_{p} = \rho*[1 - 2(\lambda_{p}\sqrt{i})^{-1} T(\lambda_{p}\sqrt{i})]^{-1}$$

$$k_{b}^{2} = (Qw/c)^{2}*[1 - 2(\lambda_{p}\sqrt{i})^{-1} T(\lambda_{p}\sqrt{i})]^{-1} *[1+2(r-1)(N_{pr}^{0.5}\lambda_{p}\sqrt{i})^{-1} T(N_{pr}^{0.5}\lambda_{p}\sqrt{i})]$$

$$T(\lambda_{p}\sqrt{i}) = J_{1}(\lambda_{p}\sqrt{i})/J_{0}(\lambda_{p}\sqrt{i})$$

$$\lambda_{p} = (1/n)*(8Sw\rho Q^{2}/\Omega\Phi)^{0.5}$$

- Impedence of fiber + air space (multilayer)

$$Z_{t} = Z_{c} * \frac{Z1*\cosh(k_{b} d) + Z_{c}*\sinh(k_{b} d)}{Z1*\sinh(k_{b} d) + Z_{c}*\cosh(k_{b} d)}$$

where $Z1 = W1 * \coth(r1 * d1)$

$W1 = \rho c$

$r1 = k = w/c$

2.2 Acoustic Mean Energy & Acoustic Energy Loss :

After solving the complex roots of wave numbers, the acoustic mean energy and acoustic energy loss are calculated by formulas defined by Blokhintsen [13] & Ko as following:

- Acoustic Mean Energy by Blokhintsen :

-- Case of two-lining duct:

$$E_{mn} = \int_{-a}^{a} N_{z} dy$$

$$= | C_{0} |^{2} (\rho c A B k^{2}) [\sinh(2Ak_{m}i)/2Ak_{m}i] *\{M[1 + (k_{m}/k)^{2} + (k_{n}/k)^{2} -(1-M^{2})(k_{mn}/k)^{2}] +2(1-M^{2}) k_{mn}/k\} \exp(-ik_{mn}L)$$

-- Case of four-lining duct:

$$E_{mn} = \int_{-b}^{b}\int_{-a}^{a} N_{z} dx dy$$

$$= | C_{0} |^{2} (\rho c A B k^{2}) [\sinh(2Ak_{m}i)/2Ak_{m}i] *[\sinh(2Bk_{n}i)/2Ak_{n}i] *\{M[1 + (k_{m}/k)^{2} + (k_{n}/k)^{2} -(1-M^{2})(k_{mn}/k)^{2}] +2(1-M^{2}) k_{mn}/k\} \exp(-ik_{mn}L)$$

where $N_{z} = (p'w'^{*} + p'^{*}w')/4 + M\{p'p'^{*}/\rho c + \rho c(u'u'^{*} + v'v'^{*} + w'w'^{*})\}/4$

- Acoustic Energy Losses by Ko:

$$\Delta PWL = 10 \log_{10} \sum_{m=0}^{\infty} \sum_{n=0}^{\infty} E_{mn}(0)/E_{mn}(L)$$

3. Numerical Method

The 4th order Runge-Kutta & modified Newton-Raphson method are applied to find the ordering complex roots. By using the real wave number of unlined duct as initial values, and plugs into the Runge-Kutta scheme to get complex initial values. The roots can he converged in about 2 -- 8 iterations with no virtual changes in the sixth decimal place by Newton-Raphson method. The Mach No. increment is kept at a value 0.1 or as large as posssible to avoid excessive computing time. The program flow of a four-lining duct explained roughly as follows :

(A) Use real wave number Kn of unlining duct as an initial value to get complex wave number Km.
(B) Use real wave number Km of unlining duct as an initial value to get complex wave number Kn.
(C) Check the residue by substituting complex values Km & Kn into equation (4) (5) or (7) (8). If the value approaches zero then stop the program, otherwise go to next steps.
(D) Use complex wave number Kn obtained from step (B) as the initial value to get complex wave number Km by the above numerical scheme.
(E) Use complex wave number Km got from step (A) as the initial value to obtain complex wave number Kn by the above numerical scheme.
(F) Reapeat step (C), and change complex wave number Kn and Km obtained from (B),(C) to (E),(D) when necessary. This process continues untill the solution converges.

4. Results and Discussion

Two groups of data listed in Table 1 are studied for two & four duct-lining. One group is for honeycomb material, and the other for fiher type material.

4.1 Two-lining of Honeycomb Material :

Fig. 2 gives the comparsion between the present computational results with the experimental data [5]. It can be seen that the agreement between the two is fairly good. Pair comparsion estimates of the mean value, standard deviation and t-distrubition value are (0.08, 0.3, 0.8). The t-distrubition value is insida the reliability range bacause it is less than the critical value 2.650, when take in 13 samplings with a significant level of 0.005 in value. So the program is right by this demostrative result.

4.2 Four-lining of Honeycomb Material :

As shown in Fig. 3 the acoustic energy loss decreases and the frequency shifts to the right as the Mach number increases when the acoustic wave propagates in the same direction with mean flow, namely downstream. On the other hand the acoustic energy loss increases and the frequency shifts to the left as the wave propages upstream. There is because the contact time between the acoustic wave and the absorption material decreases in the downstream direction owing to the convective effect and increases owing to refraction effect by maen flow. The reason of frequency shifting is owing the Doppler effect. The above results are the same as those two-lining results by Ko [5].

The acoustic energy loss becomes larger as the specific flow resistivity decreases as given in Fig.4. The frequency shift is insignificant. The above results are also the same those as two-lining results by Ko [5].

The acoustic energy loss decreases first and increases afterward in Fig. 5 as the characteristic frequency of the metal sheet increases. This is because the resonance mode changes by the different acoustic characteristics in the duct. It is therefore possible to tune the acoustic modes by adjusting thickness, hole diameter and open area ratio to effect the resonant frequency band.

Fig. 6 shows the acoustic energy loss decreases first and increases afterward and the frequency shifts to lower values when the depth increases.

Fig. 7 and Fig. 8 show the acoustic energy losses decrease when the duct length decreases or the duct heigth increases. These trends are similar to the two-lining results by Ko [5].

4.3 Two and Four-lining of Fiber Type Material :

Acoustic energy losses increase when either the Mach NO., specific flow resistivity, tortuosity, duct height decreases or the static shape factor, porosity, airgap, length increases as depicted in Fig. 9 --- 16 for four-lining ducts. Similar results appear in the two-lining ducts expect the thickness parameter. The acoustic energy loss increases when the thickness increases for the low frequency range in Fig. 17 of two-lining ducts but no clear changing in Fig. 18 of four-lining ducts bacause of larger area effect of four-lining ducts. All of them have not peak response in special band as cases as in honeycomb material.But there are good absorption effect in high frequency range.

The static shape factor is the ratio of any changable section area to the circular section area in the direct path. So the larger change in sectional area will induce more energy losses. The tortuosity is the ratio of acoustic irregular path to directpath.

The results satisfy the condition " Kozeny Constant = $2Q^2S$ ", that is a larger static shape factor (S) and a smaller tortuosity (Q) will have larger acoustic energy loss.

Because the tortuosity, static shape factor, porosity and specific flow resistivity are the parameters in the impedence model. It is necessary for taking the sensitivity analysis to evaluate their respective order of importance. The relative importance of these parameters are studied by using the basic value and 50% range data in Table 2. Their ordering of importance is porosity, tortuosity, static shape factor and specific flow resistivity as shown in Fig. 19.

4.4 Comparsion of Two & Four-lining results:

Fig. 20 and 21 show the difference of acoustic energy loss 12 dB in peak frequency and 3 dB in all frequency response for honeycomb and fiber type materials of two & four-lining respectivity. Despite of materials selected, the four-lining duct always has better results.

5. Conclusion

Duct lining is one of the most popular noise control methods. The noise reduction response, prediction and parameters study are discussed in this paper. The acoustic energy losses and frequency reoponse results are collected in Table 3 and shows that the acoustic energy loss increases as the specific flow resistivity or thickness decreases, or the charcteristic frequency of perforated metal sheet increases in honyecomb type absorption material. It increases as the specific flow resistivity or tortuosity decreases, or static shape factor, porosity or thickness increases in fiber type absorption material.

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Nomenclature

A,a	:Half of Duct Height(in)
AD,dl	:Air Gap(in)
B,b	:Half of Duct Wide(in)
C	:Sound of Speed(ft/s)
C0	:Constant
D,d	:Thickness of Material(in)
Emn	:Acoustic Mean Energy(watts)
Emn(0)	:Acoustic Mean Energy of Inlet(watts)
Emn(L)	:Acoustic Mean Energy of Outlet(watts)
F,f	:Frequency(Hz)
F0,f0	:Characteristic Frequency of Perforated Metal(Hz)

H	:Duct Height(in)
J_0	:Zero Order Bessel Function
J_1	:First Order Bessel Function
K,k	:Wave Number(ft^{-1})
k_b	:Propagation Constant
k_x, k_m	:Wave Numberin in X Direction(ft^{-1})
k_y, k_n	:Wave Numberin in Y Direction(ft^{-1})
k_z, k_{mn}	:Wave Numberin in Z Direction(ft^{-1})
k^+_x, k^+_m	:Wave Numberin in + X Direction(ft^{-1})
k^+_y, k^+_n	:Wave Numberin in + Y Direction(ft^{-1})
k^+_z, k^+_{mn}	:Wave Numberin in + Z Direction(ft^{-1})
L	:Duct Length(in)
M	:Mach Number(ft/s)
N_{pr}	:Prandtl Constant(= 0.7)
n	:Dynamic Shape Factor
P,Ω	:Porosity
p	:Sound Pressure(lb-f/m^2)
p'	:Fluctuating Sound Pressure(lb-f/m^2)
p'*	:Conjugate of Flucturing Sound Pressure (lb-f/m^2)
Q,T	:Tortuosity
R	:Specific Flow Resistivity Ratio(=R"/ρc)
R",Φ	:Specific Flow Resistivity(rayls)
r	:Specific Heat Ratio(= 1.4)
S	:Static Shape Factor
t	:Time
u_x, u_y	:Velocity in X,Y Direction(ft/s)
v	:Velocity Vector(ft/s)
u',v',w'	:Fluctuating Velocity in XYZ Direction(ft/s)
u'*	:Conjugate of Velocity in X Direction(ft/s)
v'*	:Conjugate of Velocity in Y Direction(ft/s)
w'*	:Conjugate of Velocity in Z Direction(ft/s)
w	:Angular Frequency
x,y,z	:Coordinate Position
Y_x, Y_y	:Specific Admittance of X,Y Direction
Z_x, Z_y	:Specific Impedence
Z	:Impedence(rayls)
Z_c	:Characteristic Impedence(rayls)
Z_t	:Multilayer Characteristic Impedence(rayls)
ρ	:Density(lb/m^3)
ρ'	:Fluctuating Density(lb/m^3)
∇	:Gradient
∇·	:Convergence
η	:Displacement of Particle , Variable(in)
ΔPWL	:Acoustic Energy Loss Unit same as Sound Power Level is dB L_w = 10.0*Log(W/Wref),Wref = 10^{-12} watts