中華民國音響學會
第二屆學術研討會摘要論文集

中華民國音響學會
行政院環境保護署　合辦
中華民國環境工程學會　協辦

中華民國七十八年十一月十七日

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目　　錄

Evaluation of Noise.

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Noise has been recognized as a serious environmental problem in the recent human life, and abatement of noise is an urgent work for acousticians. Noise control technology has to be based on the reasonable results of evaluation of various noises. The equivalent A-weighted sound pressure level has been accepted as a common descriptor for all kinds of noises. A number of studies have been performed in the laboratories and by the social surveys in the noise impacted areas to find out the acceptable levels or noise limits. Schultz[1] summarized results of social surveys conducted in Europe and United States. Going back to the original published data, he translated the various survey noise ratings to the relation between day and night average sound level and highly annoyed. He examined about 20 surveys performed for transportation noises. Results of 11 surveys showed remarkable consistency, but others were non-clustered as shown in Fig.1 and Fig.2 respectively. In his paper, Japanese result for Shinkansen (High Speed Rail Way) was referred. It was widely different(22 dB) from his average curve of clustered results, though it was found later that his translation was misleading, because the Japanese result was not expressed as highly annoyed.

Social surveys mentioned above were performed using various noise indices, L_{50} , $L_{eq,24}$ or NNI for aircraft noise and a variety of synonymous terms were used in attitude questions to elicit responses,those are, disturbed, bothered, annoyed or others. And the responses within that range were divided into steps of different size on 4,5,6,7 or 10 point scale and respondents selected the step by their own judgement. The different procedure and a number of steps had been a complicated problem when we tried to compare the published results, as Schultz did. In order to compare the results different surveys, it is helpful to express the respc data in terms of a common verbal and same point scale. committee of noise in the acoustical society of Japan has been engaged to establish the standard procedure for social survey.

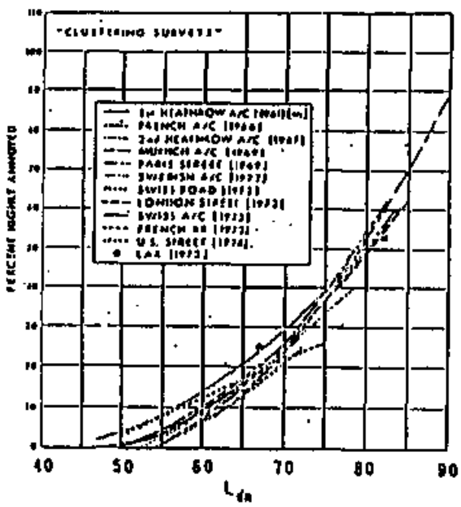

Fig.1. Clustered Results.
(from Schultz)

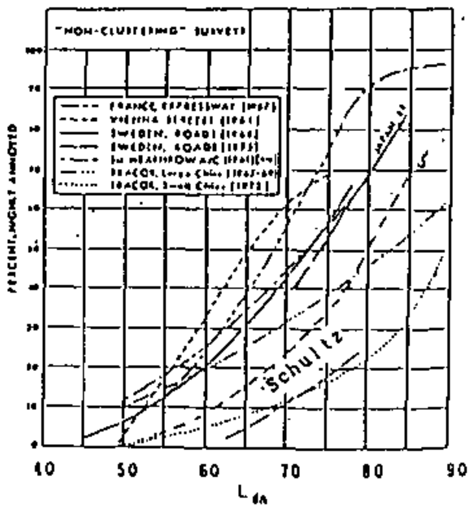

Fig.2. Non-clustered.
(from Schultz)

2. Japanese social survey.

Fig.3 shows the results for road traffic noise in Fukuoka and Nagoya cities in Japan.[2,3] The category in Nagoya survey is "bothered" (Kininaru) and divided into 4 steps, the upper end of step 4 is "very much bothered", and a percent of respondents who judged as step 4 and those of steps (1/2)3 + 4 and 3 + 4 are indicated. The results seem to be almost consistent to Schultz average curve.

However, Fig 4 and Fig.5 are

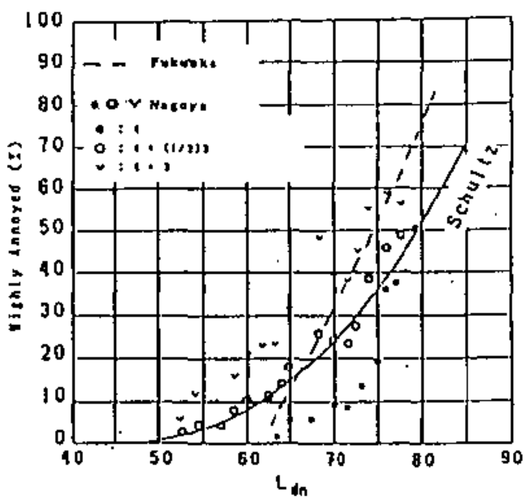

Fig.3. Road Traffic Noise

results for Aircraft[4,5] and Shinkansen[6]. The relation of annoyance to L_{dn} is so different from study to study that a close clustering is not to be expected.

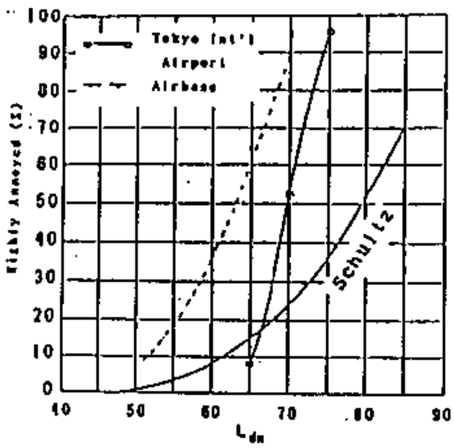

Fig.4. Aircraft Noise.

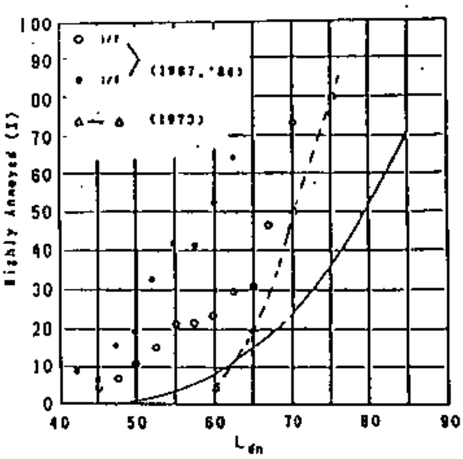

Fig.5. Shinkansen Noise.

3. Does the Social Survey reflect the effects of noise?

In the different noise surveys, the procedure of questionnaire is not always the same,and the name of response in the questionnaire and a number of steps may have effects on the result. And it is said that attitude of individual depends on many factors, such as profession, age of a respondent,and the regional condition of his home. The relation of the noise source to the individual is particularly important factor to the response. The social surveys for Shinkannsen noise at selected areas showed a big difference between areas. People of area A desired the new express line,but people of area B were negative or against for construction. These circumstances are liable to influence in the survey data. The result of social survey on noise reflects not only the effect of noise but also the judgement(satisfaction or dissatisfaction) of respondents to the noise source itself. The attitude survey data accordingly can be used for policy-making but it is very difficult to apply to the evaluation of noise. On the other hand, the experiment at the laboratory shows consistent result for different noise sources, because noise is evaluated without non-acoustical social factors.

4. Theoretical Interpretation of Social Survey Data.[7]

Last year, Fidell, Schultz and Green presented a paper in the Journal of the Acoustical Society of America.
The theoretical model assumes that a community's noise response is produced by long-term noise exposure. Individual reactions are characterized by a random variable. Individuals report a degree of annoyance when this random variable exceeds a criterion level that is not a function of acoustic factors.
First, it is assumed that the noise exposure generates an exponential distribution of annoyance. That is written as follows,

$$f(x|m)=(1/m)\exp(-x/m) \qquad (1)$$

x: the intensity of individual's noise-induced annoyance.
m: the mean of the exponential distribution of noise-dose.
A noise exposure causes annoyance when it exceeds some critical level A. The probability that a particular noise dose m leads to high annoyance is simply the integral of the probability density f(x) above A. That is,

$$P(\text{High Annoyance})=(1/m)\int_A^{\infty}\exp(-x/m)dx = \exp(-A/m) \qquad (2)$$

Next, following to the Stevens's Loudness relation, m becomes proportional to the equivalent energy of noise exposure raised the 0.3 power:

$$m=(E/E_0)^{0.3}=(10^{DNL/10})^{0.3} \qquad (3)$$

From equation (2), $\ln[P(HA)] = -A/m$

$$10\log(-\ln P(HA))=10\log A - 10\log m$$

$$= 10\log A - 0.3DNL = A^* - 0.3\,DNL \qquad (5)$$

where, $A^* = 10\log A$

If HA = (1/e) = 37 % then, $\ln P(HA)) = 0$ and $A^* = 0.3\,DNL$
Then, for DNL=80 $A^*=24$ DNL= 75 $A^* = 22.5$

Fig.6 is the relation between DNL and Percent Highly Annoyed for different A^*. The curve of $A^* = 22.5$ is the best fit to Schultz's clustered result.

Next, from Equation (3), if the 0.3 power changes to 0.6 or 1.0, the steeper response can be obtained as in Fig.7.

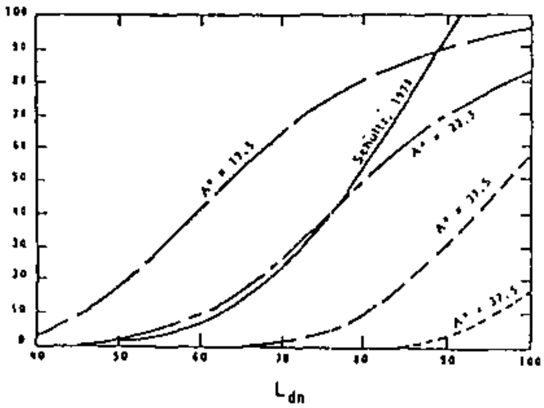

Fig.6. Effect of changing Criterion A(from Fidell)

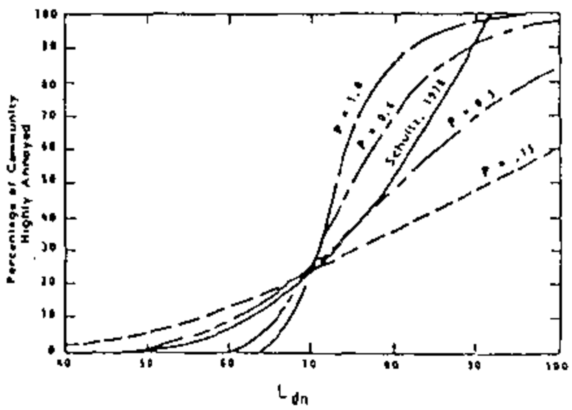

Fig.7. Effect of p of $m = (10^{DNL/10})^p$

5. Loudness as rating of noise.

Response in terms of annoyance includes various factors other than effect of noise itself. Recently, new trend for evaluation of noise has been proposed, that is the basic concept of loudness. Zwicker[8] developed a new loudness meter in place of a current sound level meter. He indicated that the A-weighted sound level is inadequate for evaluation of noise, it must be replaced by loudness calculated by his own procedure. This proposal will need further discussion, because A-weighted SPL and L_{Aeq} have been widely accepted. However, regarding to the social survey, it will be better to measure the response of people to loudness of noise instead of annoyance, because loudness may be less influenced by non-acoustical social factors.

6. NCB Curves.

For evaluation and counter-measure of noise, Beranek[9] proposed a new NCB(Balanced Noise Criterion) Curves (Fig.8) instead of NC-Curves proposed 30 years ago. NCB Curves are based on Stevens's Mark 7, and the frequency range of noise spectrum is extended to lower end of 16 Hz. The original NC-Curves were numbered as NC-40, NC-50 - -,based on Speech Interference Level(SIL) and the new NCB-Curves are also based on revised SIL (4 bands, center frequencies- 500, 1000, 3000, 4000 Hz), and balanced means the spectral balance of noise for wide range of spectrum. When low frequency components exceed those of mid-frequencies, the claim is liable to be expressed as rumble, because of the vibration of light weight structures(windows or doors)caused by low frequency noise. This criterion curves are expected to be used widely in future.

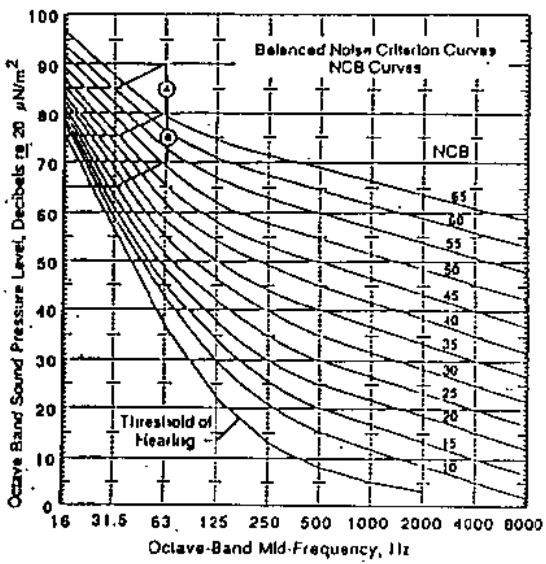

Fig.8. NCB-Curves(From Beranek)

(1) Schultz: JASA 64(1978)
(2) Kuno: JASJ(in Japanese) 40(1984)
(3) Fujimoto: JASJ 42(1986)
(4) Nishinomiya:JASJ 31(1975)
(5) Kimura:Acous.Tech. 30(1980)
(6) Transport Economics Res. Center Report 630727(1988)
(7) Fidell: JASA 84(1988)
(8) Zwicker: Noise Cont. Eng. 29(1987)
(9) Beranek:JASA 86(1989)

利用線性模式解析表面吸音處理障板之透過損失

Analysis on the Transmission Loss of Absorptive Facing panels by Linear Model

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摘要

本論文研究，首先進行吸音材料障板透過損失之理論計算，並利用線性疊加模式，求得表面吸音處理障板之透過損失。其次，再與表面吸音處理障板之透過損失實驗測定值進行比較。

本論文研究之堅硬障板表面吸音處理方式，計有面對音源與背對音源二種，而表面處理之吸音材料規格，則共有25*mm*、50*mm*厚度及32K、48K之鬆脹密度（Bulk density）等四種。根據1.6*mm*厚之鋁板與鋼板等二種堅硬金屬障板，與上述四種吸音材料所作表面吸音處理之透過損失理論計算值與對應音源之二種吸音處理方式之實驗室測定值之比較結果，顯示於表面吸音處理效果不彰之較低頻區（f ＜ 1000HZ），線性模式對表面吸音處理障板透過損失，具明顯高估。至於1000HZ以上之表面吸音處理效果良好之高頻區，當吸音材料之鬆脹密度較小時，線性模式之預估情況，以面對音源之表面處理情況較佳，其預估誤差均小於5分貝，而當表面吸音處理材料之厚度與鬆脹密度同時增大時，則除了非線性效應顯著之頻率區外，線性模式預估，則以背對音源情況較佳，其預估誤差亦小於5分貝。

一 緒論

於噪音管制工學中，利用障板與吸音材料之組合，以達到遏止或杜絕各種環境噪音之向外擴張，為一相當普遍之傳統型噪音防治方式。至於，障板及吸音材料或此二者之組合，對各種噪音之防治效果，於低頻率噪音情況，均不甚良好，而對高頻率噪音（1000HZ以上者），其對噪音源之透過損失（transmission loss），則可達30或40分貝以上［1］，甚至於厚度5*cm*之吸音材料障板，於頻率1000HZ以上時，其透過損失，亦可達9分貝以上［1］。關於上述之個別防音材料或其組合後之防音設備，其透過損失相關問題，無論在理論預估或實驗室測定，國外已發表之研究成果，不勝枚舉［1．4－8］，而吸音材料之厚度或鬆脹密度（bulk density）改變時，對不同材料障板表面吸音處理後之透過損失影響效應之相關研究，則甚為鮮少［2．3］，此為本文研究之目的。

吸音材料（absorptive materials）質地鬆軟，其與單質材料障板之力學特性，迥然而異，然其對音波傳播之物理特性，則與空氣甚為相似，而可視為一音傳之介質。於材料厚度d對音波波長λ（空氣中時）之比，$d/\lambda \ll 1$時，由於不具足夠之慣量，而無法達到阻遏音波穿透之效果

，其透過損失或對音波音壓量之衰減值，近乎等於零［ 1 ］（此為與堅硬防音障板最大差別之處），但當上述之 d / λ ≈ 0（1）時，則厚度不大之吸音材料，卻已具堅硬障板之防音特性。其透過損失大於 10 分貝［ 1 ］，以 30cm、10k 之吸音玻璃棉為例（其表面密度為 3kg / m^2，於頻率 1000HZ 時，其透過損失可達 60 分貝［ 1 ］，此相當於此吸音材料障板 50 倍重量的水泥牆之透過損失（此水泥牆於 250HZ 之頻率時，其透過損失可達 42 分貝，但上述之玻璃棉則僅及於 10 分貝左右）［ 1 ］，故於 1000HZ 以上之頻率，微薄之吸音材料，對堅硬障板之表面吸音處理，將可大大提高障板之透過損失。本計劃研究，主要在探討吸音材料厚度或鬆脹密度（ bulk density ）之改變，對不同金屬單質材料障板，其表面吸音處理對上述障板透過損失之影響效應。

根據以上之研究目的，本文之研究內容，包括單獨吸音材料透過損失之理論計算，利用線性模式預估表面吸音處理障板之透過損失，以及不同吸音材料對不同金屬材料障板表面吸音處理時，其透過損失之實驗室測定，與上述線性理論預測結果之比較。

研究結果顯示於 1000HZ 之頻率以下，吸音材料對堅硬障板透過損失之影響不明顯，故理論預估與實驗室測定結果，無比較之意義。至於，表面吸音處理對障板透過損失改善效果明顯之高頻率區域（ f ≥ 1000HZ ），於較小鬆脹密度及厚度之表面吸音處理，此線性疊加模式之預估，對面對音源之表面吸音處理情況較佳，而當此鬆脹密度或吸音棉厚度增大時，此種較佳預估之情況，有轉移至背對音源之表面吸音處理情況（除了 48k、5.0cm 吸音棉對鋼板之背對音源吸音處理情況，於 f ≈ 1600HZ 附近所發生之穿透損失驟增情形，此時線性疊加模式亦已無法預估表面吸音處理後障板之透過損失。）

二　表面吸音處理障板透過損失之線性理論計算

2.1　吸音材料障板之透過損失理論計算

吸音材料（ absorptive materials ）具多孔性（ porosity ）且質地鬆軟，其對聲波之音傳特性，仍可如空氣視之為一傳播媒介。因其具多孔性及較高密度，故其對聲波能量之耗損，不可以空氣之情況，而忽視之。於低頻長波情況，吸音材料仍不具足夠慣性，以阻尼聲波之傳動，其對聲波能量之衰減（ attenuation ）可忽略不計，故對質硬障板之表面吸音處理，則未能有效地改善原始障板之防音效果。於吸音材料厚度對入射波長比接近或大於 1/10 之高頻率短波情況，此吸音材料已具足夠慣性，阻尼聲波之傳動，故可視為一半硬（ semi-rigid ）或堅硬材料，其對堅硬障板之表面吸音處理，將可大大提高原始障板之透過損失［ 1 ］（有關吸音材料之物理與材料力學特性及相關之音響特性，詳見參考文獻［ 1 ］及［ 9 ］）。

依圖 1 所示當 $Pe^{i\omega t}$ 之聲波入射於厚度 d 之吸音材料障板，則其於材料內之音壓分佈，可假定為

$$P_a = Pe^{i(\omega t - k_a x)}$$

其中

$k_a = \beta - \alpha i$ 為音傳複常數
(complex wave propagntion constant)

$$P_a = Pe^{-\alpha x} e^{i(\omega t - \beta x)} \quad (2.2)$$

而

$$P_a|_{x=d} = Pe^{-\alpha d} e^{i(\omega t - \beta d)} \quad (2.3)$$

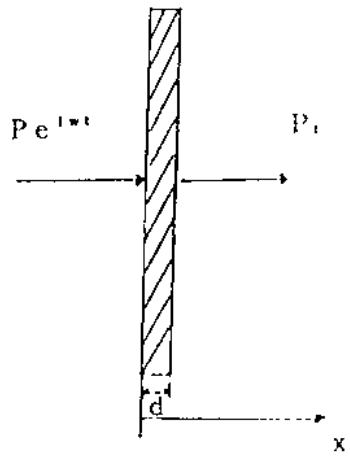

圖 1　吸音材料障板之聲傳示意圖

由遮音物體之透過損失定義，吸音材料對音傳之透過損失為

$$TL = 10 \log \frac{I_{in} S}{I_t S} \quad (2.4)$$

$$I_{in} = \frac{P^2}{2\rho_0 C} \qquad I_t = \frac{P^2 e^{-2\alpha d}}{2\rho_0 C}$$

即 $TL = 20\ \alpha d \log e = 8.69\ \alpha d (dB)$ (2.5)

(2.5) 之 TL 僅為吸音障板透過損失之大部份，而非全部。嚴格而言，吸音障板之全部透過損失為 (2.5) 之 TL 與介面音響阻抗不連續所造成透過損失之總和。由於上述介面音響阻抗 (Acoustic impendance) 所造成之音傳透過損失較 (2.5) 之 TL，可忽略不計 [1]，故一般吸音材料透過損失之理論預估，僅須計算 (2.5) 之 TL 值。

本文研究所選取之吸音材料，係由民間廠商百塑公司提供之 32k 與 48k，厚度 25mm、50mm 之正玻璃棉，其有關之物理特性及相關之音響係數如聲波波長與衰減係數之計算，詳見文獻 [9]。根據文獻 [9]，上述 4 種不同規格吸音材料透過損失，可求得如表一所示。

2.2　表面吸音處理障板透過損失之線性理論預估

相同規格厚度之吸音材料，對不同堅硬障板之表面處理，所造成透過損失改變，因受處理障板之材料不同，而有甚大差異 [2]，故表面吸音處理對障板透過損失之效應，將為一非線性問題，其非線性解析模式甚難求得。基於定性解析觀點，當上述非線性效應不甚明顯時，線性解析模式，亦可作為表面吸音處理障板透過損失之定性預估。

表一　32k 與 48k 正玻璃棉於厚度2.5及5.0 cm之透過損失（αd）（dB）

f（HZ）		125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000
32 K	25 mm	1.05	1.29	1.62	1.85	2.37	2.73	3.1	3.45	3.93	4.24	4.58	4.94	5.72	6.44	5.41	[illegible]
	50 mm	2.1	2.59	3.24	3.70	4.73	5.47	6.2	6.98	7.86	8.48	9.16	9.88	10.43	12.58	11.61	11.67
48 K	25 mm	1.14	1.37	2.0	2.4	2.925	3.34	4.28	4.865	5.47	6.08	6.69	7.57	8.25	8.3	9.24	10.0
	50 mm	2.28	2.73	4.0	4.81	5.55	6.08	8.55	[illegible]	[illegible]	12.16	13.38	15.1	16.5	16.5	[illegible]	[illegible]

本文研究將對線性模式預估值及實驗室測定結果，作不同情況下之比較，以探討線性解析模式之適用情形。

依圖2所示，若不考慮表面處理吸音材與受處理障板間之非線性耦合，則直接作用於受處理障板之音壓大小為

$$P_{in} = P_{in} e^{-\alpha d} e^{i(\omega t - \beta d)} \quad (2.6)$$

而射入於其上之音能為

$$(W_{in})_B = \frac{P_{in}^2 \; e^{-2\alpha d}}{2\rho_0} \cdot S \quad (2.7)$$

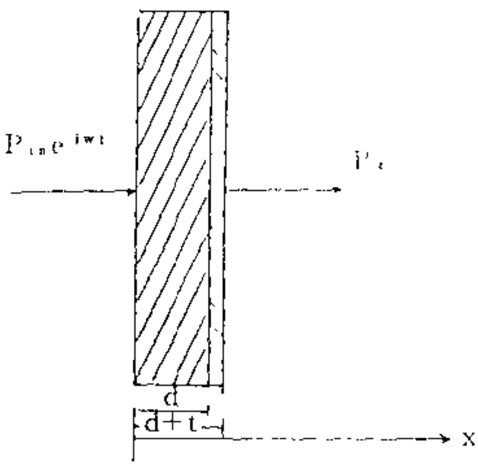

圖2　表面吸音處理障板受音波之入射及穿透示意圖

設未受處理障板之透過損失為（TL）$_B$，故其穿透音能為

$$W_t = 10^{-\frac{(TL)}{10}} (W_{in})_B = 10^{-\frac{(TL)}{10}} \frac{P_{in}^2 \; e^{-2\alpha d}}{2\rho c} \cdot S \quad (2.8)$$

根據定義，表面處理障板之透過損失為

$$(TL)_t = 10 \log \frac{W_{in}}{W_t} \quad (2.9)$$

$$W_{in} = \frac{P_{in}^2}{2\rho c} \quad (2.10)$$

將（2.8），（2.10）代入（2.9），則

$$(TL)_t = (TL)_B + 20\alpha d \log e$$
$$= (TL)_B + 8.69\alpha d \qquad (2.11)$$

（2.11）式中，$(TL)_B$ 為未受表面吸音處理前之障板透過損失，而 $8.69\alpha d$ 則為吸音障板之透過損失。

三　障板透過損失之實驗室測定

3.1　單獨障板透過損失之實驗室測定

有關本研究所選取厚度 1.6*mm* 鋁質與 1.7*mm* 鋼質障板，其透過損失測定，係採用國立台灣大學造船研究所音響實驗室之單一迴響室聲音強度法（有關本測定方法之實驗理論、測定方法之相關設備與儀具佈置，以及測定條件等相關細節，詳見文獻［10］、［11］）。根據上述單一迴響室聲音強度法，所求得 1.6*mm* 鋁質與 1.7*mm* 鋼質障板之透過損失測定結果，詳見文獻［9］。

3.2　表面吸音處理障板之透過損失實驗室測定

循 3.1 節之單一迴響室聲音強度法，進行 32k、48k 與 25*mm*、50*mm* 等四種不同組合吸音材料，對上述二種障板，於面對音源或背對音源之表面處理時，其透過損失之實驗室測定。有關上述二種障板，於八種不同表面吸音處理情況之透過損失測定結果，詳見文獻［9］。

四　結果討論與結論

4.1　結果討論

將 3.1 節所測得之單獨障板透過損失 $(TL)_B$ 與表一之吸音材料透過損失理論值 αd(dB) 相加，可得表面吸音處理障板透過損失線性模式預測值（詳細結果，參見文獻［9］）。利用上述之線性模式預測值與 3.2 節之表面吸音處理障板透過損失測定值，作結果比較，可徹底了解線性模式預估之適用範圍。

根據文獻［9］，表面吸音處理障板透過損失實驗室測定值與線性模式預測值結果之詳細比較，顯示 1000HZ 以下之吸音處理效果不明顯之低頻區，上述之透過損失線性模式預測值，並無任何實質意義。而 1000HZ 以上之吸音處理效果良好之高頻區，當表面吸音處理材料厚度與鬆脹密度均小時，上述二種被處理障板之透過損失，均以面對音源之處理情況與線性模式預估值較吻合，其預估誤差小於 5 分貝（有關個案之比較結果，見圖 3、4）。至於吸音材料厚度與鬆脹密度同時增大時，則上述之吻合趨勢，除了鋼材障板在 48k 5*cm* 之玻璃棉背對音源表面吸音處理情況，於頻率 1600HZ 附近所發生之透過損失驟增現象外，有逐漸轉移至背對音源之表面吸音處理情況。以上預估誤差，若不考慮透過損失驟增現象，則亦均小於 5 分貝（相關之個案比較結果，見圖 5、6）

4.2　結　論

1. 1000HZ 以不之低頻區，表面吸音處理對障板透過損失之改善不明顯，

線性模式預測值，無實質意義。

2. 1000HZ 以上之高頻區，表面吸音處理材料之厚度與鬆脹密度均小時，線性模式預估值與面對音源之表面吸音處理障板透過損失測定值較吻合。其預估之誤差小於 5 分貝。

3. 1000HZ 以上之高頻區，表面吸音處理材料之厚度與鬆脹密度，均同時增大時，線性模式預估結果與背對音源處理情況之透過損失測定結果較吻合（透過損失驟增情況除外），其預測誤差小於 5 分貝。

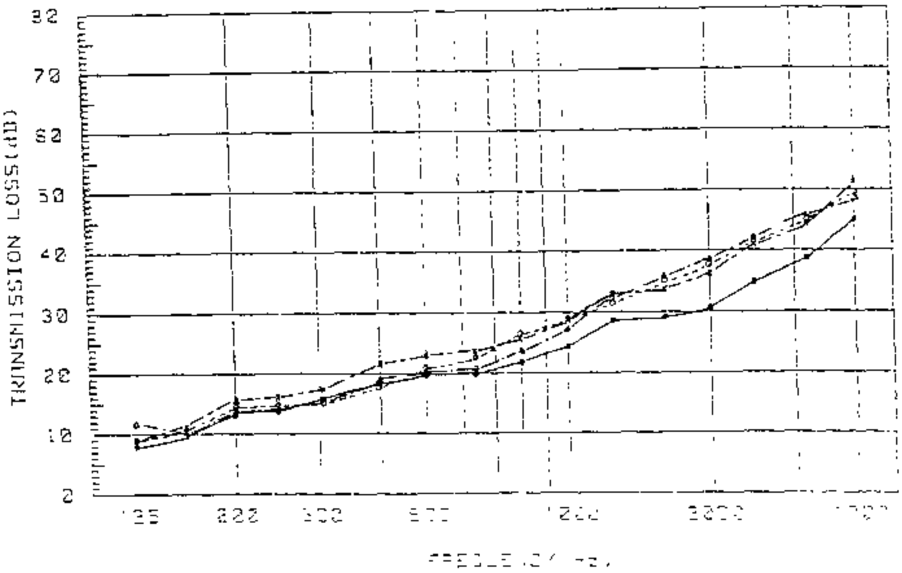

圖 3　0.15cm 厚鋁材障板受 32k、2.5cm 玻璃棉之表面吸音處理，其透過損失之實驗測定與線性理論預估之比較（。……。：面對音源，△ -·- △：背對音源，X ----- X：線性預估）

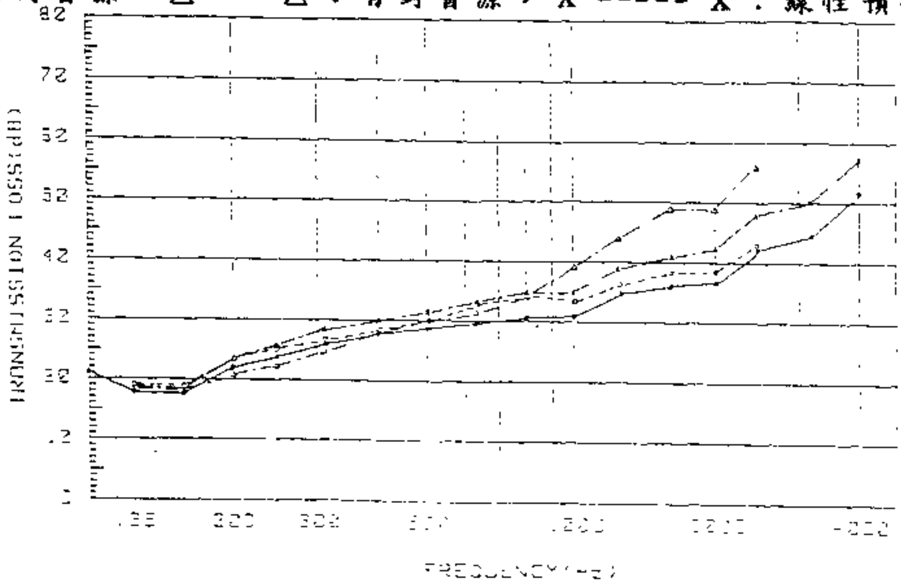

圖 4　厚度 0.15cm 鋼板受 2.5cm、32k 玻璃棉之表面吸音處理，其透過損失測定值與線性理論預估之比較（。…… 。：面對音源，△ -·- ：背對音源，X — — —：線性預估。

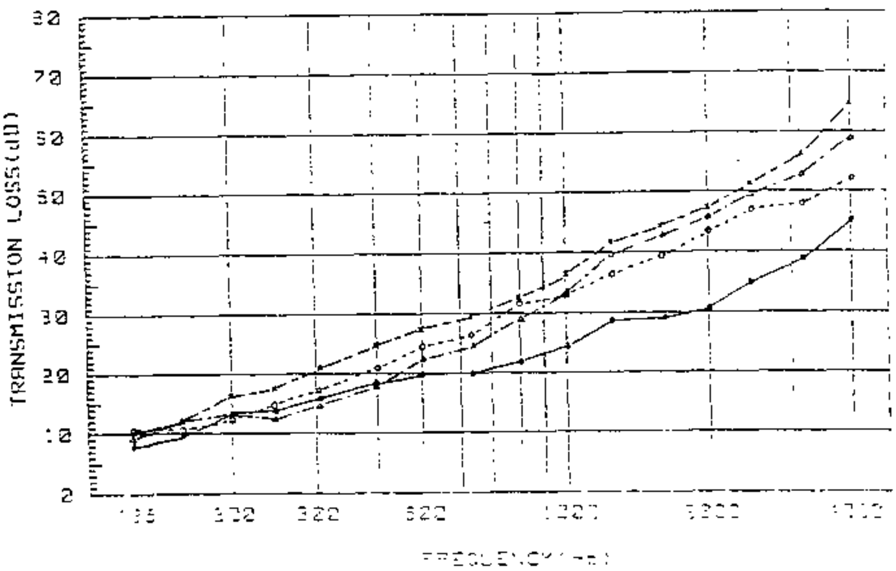

圖 5　厚度0.15*cm*鋁材障板受5*cm*、48k玻璃棉表面吸音處理，其透過損失測定值與線性理論預估之比較（。……。：面對音源，△—·—△：背對音源，X—·—X：線性預估）

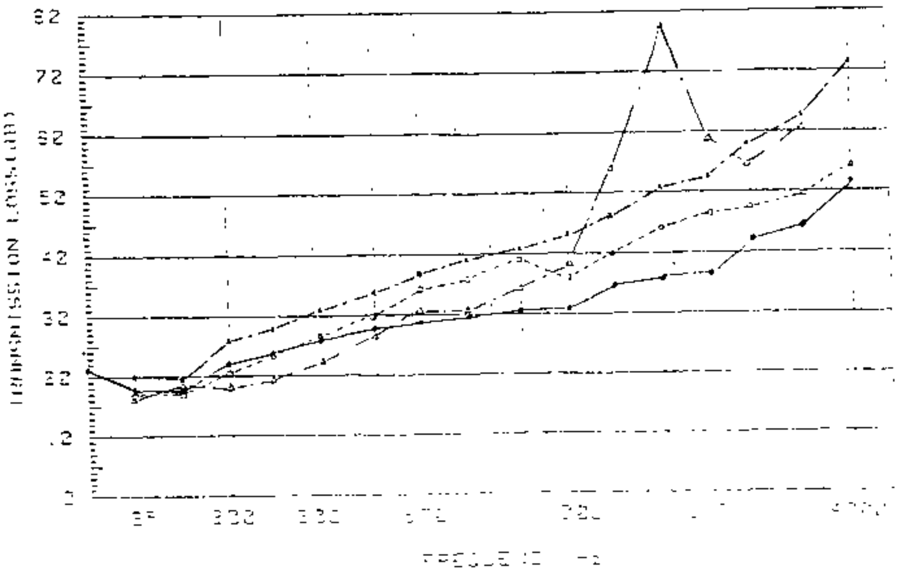

圖 6　厚度0.15*cm*鋼材障板受5*cm*、48k玻璃棉之表面吸音處理，其透過損失測定與線性理論預估之比較（。……。：面對音源，△—·—：背對音源，X—·—X：線性理論）

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