

NORMAL INCIDENCE ABSORPTION COEFFICIENTS AND ACOUSTIC IMPEDANCES OF SINGLE LAYER PERFORATED SHEET LINERS

1. NOTATIONS

a_0	speed of sound in free air	m/s	ft/s
d	thickness of perforate	m	ft
f	frequency of incident sound wave	Hz	Hz
f_0	resonant frequency of perforate/air gap combination (liner)	Hz	Hz
L_i	spectrum level of incident acoustic pressure at frequency f	dB*	dB*
l	depth of air gap	m	ft
M_L	liner inertance	m	ft
p_i	incident acoustic pressure at frequency f	N/m ²	lbf/ft ²
p_0	atmospheric pressure	N/m ²	lbf/ft ²
R_A	specific acoustic resistance of liner	N s/m ³	lbf s/ft ³
r	perforate hole radius	m	ft
u_0	air velocity in perforate hole	m/s	ft/s
X_A	specific acoustic reactance of liner	N s/m ³	lbf s/ft ³
Z_A	specific acoustic impedance of liner	N s/m ³	lbf s/ft ³
α_N	normal incidence absorption coefficient of liner		
γ	ratio of specific heat capacities of air		
μ	pressure amplitude parameter, $p_i(1 - \sigma^2)/\gamma p_0 \sigma^2$		
ρ_0	density of free air	kg/m ³	slug/ft ³
σ	open area ratio, i.e. area of holes per unit area of perforate		

* The reference pressure for all decibels is $20 \mu \text{N/m}^2$ (0.0002 dyn/cm^2 or $0.42 \times 10^{-6} \text{ lbf/ft}^2$).

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2. NOTES

This Data Item gives a method for estimating the normal incidence absorption coefficients and acoustic impedances of thin, single layer, perforated sheet liners commonly used to line aircraft gas turbine propulsion ducts. The materials considered are spaced from a solid backing sheet by a honeycomb layer. The separation between the perforated sheet and the backing sheet determines the frequency response of the liner. The absorption coefficients and acoustic impedances can be estimated for incident spectrum levels up to 150 dB in zero flow, which may represent an overall sound pressure level of 160 – 165 dB.

In the theory on which this Data Item is based, the normal incidence absorption coefficient and acoustic impedance of the liner are derived in terms of its basic physical properties.

The data presented are confirmed by available test data for frequencies between 1.5 kHz and 6.0 kHz, for air gaps up to 50 mm (2 in), for perforate thicknesses up to 2.5 mm (0.1 in), for open area ratios up to 0.3 and for incident spectrum levels up to 150 dB. The experimental support for the theory is confined to normal temperatures and pressures. Within these ranges of variables, the 95 per cent confidence limits obtained from the experimental data are ± 0.1 from the calculated absorption coefficients.

3. CALCULATION PROCEDURE

The procedures for using this Data Item are illustrated by the examples but a typical procedure for estimating α_N may be as follows.

- (i) Calculate $\sigma l/d$ and r/d and from Figure 1 read off $f_0 l/a_0$.
- (ii) Calculate f_0 and f/f_0 for the frequencies required.
- (iii) Read off u_0/a_0 for the required value of σ from Figures 2a to 2d and then $M_L/2r$ from Figure 3.
- (iv) Calculate $X_A/\rho_0 a_0$, given by

$$X_A/\rho_0 a_0 = (2\pi f M_L/a_0) - \cot(2\pi f l/a_0). \quad (3.1)$$

- (v) Read off p_i from Figure 4 and calculate μ from $\mu = p_i(1 - \sigma^2)/\gamma p_0 \sigma^2$.
- (vi) From Figure 5 read off $R_A/\rho_0 a_0$.
- (vii) Then $Z_A/\rho_0 a_0 = R_A/\rho_0 a_0 + iX_A/\rho_0 a_0$.
- (viii) From Figure 6 read off α_N .

4. DERIVATION AND REFERENCES

Derivation

The Derivation lists selected sources that have assisted in the preparation of this Data Item.

1. BERANEK, L.L. *Noise Reduction*. Chapter 16, McGraw-Hill Book Co. Inc., 1960.
2. INGARD, U.
ISING, H. Acoustic non-linearity of an orifice. *J. Acoust. Soc. Am.*, Vol. 42, No. 1, pp.6–17, 1967.
3. INGARD, U. Absorption characteristics of non-linear acoustic resonators. Letter to *J. Acoust. Soc. Am.*, Vol. 44, No. 4, pp.1155–56, 1968.
4. – Unpublished reports on the acoustic properties of perforated liners at high sound intensities. Rolls Royce (1971) Ltd, February 1971.

References

The References given are recommended sources of information supplementary to that in this Data Item.

5. ZWIKKER, C.
KOSTEN, C.W. *Sound absorbing materials*. Elsevier Publishing Company, Amsterdam, 1949.
6. INGARD, U. Side branch resonators in ducts. Bolt, Beranek and Newman Inc., (unpublished).

5. EXAMPLES

- 5.1 It is required to estimate the acoustic impedance ratio for a perforated sheet liner, at a frequency of 4000 Hz, when subjected to sound pressure levels between 120 dB and 150 dB.

The relevant parameters are

$$\begin{aligned}
 a_0 &= 340 \text{ m/s}, & r &= 0.635 \text{ mm}, \\
 d &= 0.56 \text{ mm}, & \gamma &= 1.4, \\
 \sigma &= 0.1, & \rho_0 &= 1.225 \text{ kg/m}^3, \\
 l &= 25.4 \text{ mm}, & p_0 &= 101.3 \times 10^3 \text{ N/m}^2.
 \end{aligned}$$

The calculation is carried out according to the procedure in Section 3.

(i) Then $\frac{\sigma l}{d} = 4.54$ and $\frac{r}{d} = 1.13$.

Therefore from Figure 1, $\frac{f_0 l}{a_0} = 0.164$.

(ii) Hence $f_0 = \frac{0.164 \times 340}{0.0254}$,

$$= 2195 \text{ Hz.}$$

Therefore $\frac{f}{f_0} = \frac{4000}{2195},$

$$= 1.822.$$

(iii) and (iv) Thus from Figures 2d and 3 and Equation (3.1) the following table is constructed in order to estimate $X_A/\rho_0 a_0$.

$L_i(\text{dB})$	120	130	140	150
u_0/a_0	0.017	0.043	0.107	0.24
$M_L/2r$	8.55	8.55	8.30	6.25
$M_L(m)$	0.0109	0.0109	0.0105	0.0079
$\frac{2\pi f M_L}{a_0}$	0.81	0.81	0.78	0.59
$\cot \frac{2\pi f l}{a_0}$	-0.32	-0.32	-0.32	-0.32
$X_A/\rho_0 a_0$	1.13	1.13	1.10	0.91

(v) Now from Figure 4 read off p_i and calculate μ as follows.

$L_i(\text{dB})$	120	130	140	150
$p_i(\text{N/m}^2)$	20	63	200	630
μ	0.014	0.044	0.14	0.44

- (vi) From Figure 5 read off $R_A/\rho_0 a_0$ and calculate $Z_A/\rho_0 a_0$ from Equation (3.2) as follows.

$L_i(\text{dB})$	120	130	140	150
$X_A/\rho_0 a_0$	1.13	1.13	1.10	0.91
$R_A/\rho_0 a_0$	0.01	0.02	0.10	0.47
$Z_A/\rho_0 a_0$	$0.01 + i1.13$	$0.02 + i1.13$	$0.10 + i1.10$	$0.47 + i0.91$

- 5.2 It is required to estimate the normal incidence absorption coefficient for the perforate given in Example 5.1 at the 1/3-octave centre frequencies between 1600 and 5000 Hz at a sound pressure level of 150 dB.

As in Example 5.1

and $\mu = 0.44$,
 $f_0 = 2195 \text{ Hz}.$

Calculate f/f_0 and use Figures 2d and 3 and Equation (3.1) to estimate $X_A/\rho_0 a_0$. Then use Figures 4 and 5 to estimate $R_A/\rho_0 a_0$ and Figure 6 to estimate α_N . The following table is then constructed.

$f(\text{Hz})$	1600	2000	2500	3150	4000	5000
f/f_0	0.729	0.911	1.139	1.435	1.822	2.278
u_0/a_0	0.250	0.260	0.270	0.262	0.240	0.204
$M_L/2r$	6.10	5.90	5.70	5.80	6.20	6.85
$M_L(\text{m})$	0.0077	0.0075	0.0072	0.0074	0.0079	0.0087
$\frac{2\pi f M_L}{a_0}$	0.23	0.28	0.33	0.43	0.58	0.80
$\cot \frac{2\pi f l}{a_0}$	1.07	0.73	0.42	0.09	-0.32	-0.98
$X_A/\rho_0 a_0$	-0.84	-0.45	-0.09	0.34	0.90	1.78
$R_A/\rho_0 a_0$	0.28	0.32	0.33	0.32	0.28	0.22
α_N	0.46	0.64	0.74	0.70	0.43	0.19