

NORMAL INCIDENCE ABSORPTION COEFFICIENTS AND ACOUSTIC IMPEDANCES OF TYPICAL SINGLE LAYER FIBROUS LINING MATERIALS

1. NOTATION

a_0	speed of sound in free air	m/s	ft/s
d	thickness of fibrous material	m	ft
f	frequency of incident sound wave	Hz	Hz
f_0	resonant frequency of fibrous material/air gap combination (liner)	Hz	Hz
h	porosity of fibrous material, $1 - (\rho_s/\rho_f)$		
L_i	spectrum level of incident acoustic pressure at frequency f	dB*	dB*
l	depth of air gap	m	ft
p_i	incident acoustic pressure at frequency f	N/m ²	lbf/ft ²
R_A	specific acoustic resistance of liner	N s/m ³	lbf s/ft ³
R_1	flow resistance of fibrous material at surface velocity V_1	N s/m ³	lbf s/ft ³
R_2	flow resistance of fibrous material at surface velocity V_2	N s/m ³	lbf s/ft ³
r	average pore radius of fibrous material	m	ft
V_1	lower reference flow velocity normal to liner surface; used to define non-linearity factor, usually 0.2 m/s (0.656 ft/s)	m/s	ft/s
V_2	upper reference flow velocity normal to liner surface, used to define non-linearity factor, usually 5 m/s (16.4 ft/s)	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		
β	non-linearity factor of fibrous material, R_2/R_1		
η	dynamic viscosity of air	kg/m s	slug/ft s
ϵ	velocity ratio, V_2/V_1		

For footnote refer to end of Notation Section

Issue June 1973
With Amendment A, November 1976

ρ_0	density of free air	kg/m ³	slug/ft ³
ρ_f	density of fibres of fibrous material	kg/m ³	slug/ft ³
ρ_s	density of fibrous material	kg/m ³	slug/ft ³

* The reference pressure for all decibels is 20 μ N/m² (0.0002 dyn/cm² or 0.42×10^{-6} lbf/ft²).

2. NOTES

This Data Item gives a method of estimating the normal incidence absorption coefficients and acoustic impedances of fibrous materials (e.g. fibremetals and polyimide laminates) 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 fibrous material 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 160 dB in the absence of air flow.

In the theory on which this Data Item is based the real and imaginary parts of the specific acoustic impedance ratio ($R_A/\rho_0 a_0$ and $X_A/\rho_0 a_0$ respectively) are derived in terms of the basic physical properties of the material and of the noise environment in which it is placed. Experimental results show that only the acoustic resistance of the material varies with increasing incident sound pressure level, and that only the acoustic reactance of the material varies with the frequency of the incident sound pressure level. These observations are assumed in developing the theory. The parameters required to calculate the normal incidence absorption coefficient of a fibrous liner are normally given by the manufacturer but if the flow resistance and porosity are not available they may be measured using the methods set out in Reference 9. The normal incidence absorption coefficient of the liner may also be calculated from measured values of the real and imaginary parts of the acoustic impedance.

The data presented are confirmed by available test data for frequencies between 1 kHz and 6.5 kHz, for air gaps between 6 mm (0.25 in) and 50 mm (2 in), for fibrous material thicknesses up to 1.5 mm (0.06 in), for porosities up to 0.8, for incident spectrum levels up to 160 dB, and for normal temperatures and pressures. This Data Item should be used with caution outside these limits.

The calculated absorption coefficients can be expected, with a 95 per cent confidence, to be within ± 0.1 of the measured values.

3. CALCULATION PROCEDURE

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

- (i) From Figure 1 read off p_i .
- (ii) Calculate $R_1/(\rho_0 a_0)[1 - (\beta - 1)/(\epsilon - 1)]$ and $p_i R_1(\beta - 1)/\rho_0^2 a_0^2 V_1(\epsilon - 1)$ and from Figure 2 read off $R_A/\rho_0 a_0$.
- (iii) Calculate $4R_1 dh/\rho_0 \alpha_0 l$, and from Figure 3 read off $f_0 l/a_0$, and hence calculate f_0 .

- (iv) Calculate f/f_0 and from Figure 4, or using

$$X_A/\rho_0 a_0 = (f/f_0)[\cot(2\pi f_0 l/a_0)] - \cot(2\pi f l/a_0),$$

estimate $X_A/\rho_0 a_0$.

- (v) Then $Z_A/\rho_0 a_0 = R_A/\rho_0 a_0 + i(X_A/\rho_0 a_0)$.

- (vi) Read the normal incidence absorption coefficient from Figure 5. For large values of $R_A/\rho_0 a_0$ and $X_A/\rho_0 a_0$ the value of α_N may be calculated using

$$\alpha_N = 4(R_A/\rho_0 a_0)/[(R_A/\rho_0 a_0 + 1)^2 + (X_A/\rho_0 a_0)^2].$$

4. DERIVATION AND REFERENCES

Derivation

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

1. VAN DEN DIJK, J. Sound absorbing materials. *Appl. Sci. Res. B*, Vol. 1, pp.50-62, 1947.
KOSTEN, C.W.
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2. ZWIKKER, C. *Sound absorbing materials*. Elsevier Publishing Company, Amsterdam, 1949.
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3. INGARD, U. Acoustic non-linearity of an orifice, *J. Acoust. Soc. Am.*, Vol. 42, No. 1, pp.6-17, 1967.
ISING, H.
4. MARSH, A.H. A study of turbofan engine compressor noise suppression techniques.
et al. NASA CR-1056, June 1968.
5. WALTON, R.H. Acoustic properties of materials for use in engine turbofan linings.
MANGIAROTTY, R.A. Boeing Co. Document D6-22746-TN, December 1968.
6. MARSH, A.H. Investigation of DC-8 nacelle modifications to reduce fan-compressor noise in airport communities. Part II Design studies and duct lining investigations. NASA CR-1706, December 1970.
7. – Study and development of turbofan nacelle modifications to minimise fan compressor noise radiation. Vol. II Acoustic lining development. NASA CR-1712, January 1971.
8. – Unpublished reports on the acoustic impedance of fibrous metallic 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.

9. BERANEK, L.L. *Noise Reduction*. Chapter 12, McGraw-Hill Book Co. Inc., 1960.

10. MORSE, P.M. *Vibration and Sound*. 2nd Edition, McGraw-Hill Book Co. Inc., 1948.
11. DELANY, M.E.
BAZLEY, E.N. Acoustical properties of fibrous absorbant materials. *Appl. Acoust*, Vol. 3, No. 2, pp.105-116, 1970.
12. EGOROV, N.F. Sound absorption by thin layers of fibrous materials. *Sov. Phys. - Acoust*, Vol.15, No.2, pp.189-191, 1969.

5. EXAMPLES

- 5.1 It is required to estimate the normal incidence absorption coefficient for a sample of fibremetal, at a frequency of 5000 Hz, when subjected to noise levels between 120 dB and 160 dB.

The relevant parameters are as follows:

$$\begin{array}{ll}
 a_0 = 340 \text{ m/s}, & V_1 = 0.2 \text{ m/s}, \\
 d = 1 \text{ mm}, & V_2 = 5.0 \text{ m/s}, \\
 f = 5000 \text{ Hz}, & \beta = 3.16, \\
 h = 0.43, & \eta = 17.9 \times 10^{-6} \text{ kg/m s}, \\
 l = 25.4 \text{ mm}, & \rho_0 = 1.23 \text{ kg/m}^3, \\
 R_1 = 250 \text{ N s/m}^3, & \epsilon = 5/0.2 = 25. \\
 r = 0.02 \text{ mm}, &
 \end{array}$$

Following steps (i) and (ii) of the procedure in Section 3, for a range of values of L_i between 120 dB and 160 dB, p_i is read from Figure 1 and, using the following table, values of $R_A/\rho_0 a_0$ are read from Figure 2.