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Estimation of r.m.s. strain in laminated skin panels subjected to random acoustic loading

Associated software: ESDUpac A8408

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The Royal Aeronautical Society

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THE PREPARATION OF THIS DATA ITEM

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ESTIMATION OF R.M.S. STRAIN IN LAMINATED SKIN PANELS SUBJECTED TO RANDOM ACOUSTIC LOADING

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1. NOTATION

a	length of plate in x-direction (see Sketch 1.1)	m	in
b	length of plate in y-direction, or arc length of curved plate	m	in
D	flexural stiffness sub-matrix for plate [see Equation (2.1)]	N m	lbf in
E_x, E_y	plate Young's modulus of elasticity in x- and y-directions, respectively	N/m^2	lbf/in^2
E_α, E_β	lamina Young's modulus of elasticity in α- and β-directions, respectively	N/m^2	lbf/in^2
f_n	fundamental natural frequency of skin plate assuming all edges fixed	Hz	Hz
$G_p(f_n)$	spectral density of acoustic pressure at frequency f_n	$(N/m^2)^2/Hz$	$(lbf/in^2)^2/Hz$
$G_{\alpha\beta}$	shear stiffness of lamina in (α, β) direction	N/m^2	lbf/in^2
K	$\begin{bmatrix} \partial^2 w/\partial x^2 \\ \partial^2 w/\partial y^2 \\ 2\partial^2 w/\partial x \partial y \end{bmatrix}$ column sub-matrix of curvature components of plate [see Equation (2.1)]	m^{-1}	in^{-1}
K_c	curved plate correction factor for strains in y-direction		
K_p	plate correction factor		
K_δ	damping ratio correction factor		
$L_{ps}(f_n)$	spectrum level of acoustic pressure at frequency f_n	dB*	dB
M	$\begin{bmatrix} M_x \\ M_y \\ M_{xy} \end{bmatrix}$ column sub-matrix of bending moment intensities acting in xz- and yz-planes and twisting moment intensities acting about x- and y-axes, respectively	N m/m	lbf in/in
N	number of layers in plate		

For footnotes refer to end of Notation Section

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R	plate mean radius	m	in
S_o	ratio of stress at a point in surface of plate in assumed mode to applied uniform static pressure on plate		
S_{rms}	r.m.s. stress on surface of plate due to acoustic loading	N/m^2	lbf/in^2
t	laminated plate thickness	m	in
w	deflection of plate normal to *xy*-plane	m	in
x, y	plate coordinate system (see Sketch 1.1)		
α, β	lamina coordinates aligned with principal axes of orthotropy of lamina (see Sketch 1.2)		
δ	equivalent viscous damping ratio of fundamental mode of plate		
ε_{fn}	r.m.s. strain deduced from r.m.s. stress given by Equation (2.3)†		
ε_{rms}	r.m.s. strain in surface of plate due to acoustic loading [see Equation (2.4)]		
ν_{xy}	Poisson's ratio for plate resulting from load applied in *x*-direction		
ν_{yx}	Poisson's ratio for plate resulting from load applied in *y*-direction		
$\nu_{\alpha\beta}$	Poisson's ratio for lamina resulting from load applied in α-direction		
$\nu_{\beta\alpha}$	Poisson's ratio for lamina resulting from load applied in β-direction		
ψ	angle of principal axis of orthotropy, α, for lamina measured from plate principal axis, *x* (see Sketch 1.2)	degree	degree

* The reference pressure for sound levels expressed in decibels is 20 $\mu N/m^2$.

† ε_{fn} is predicted assuming a single (fundamental) mode of response to random acoustic loading.

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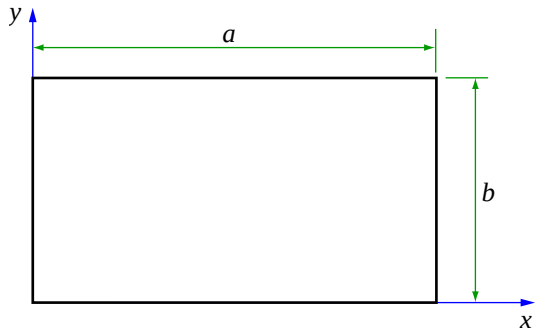
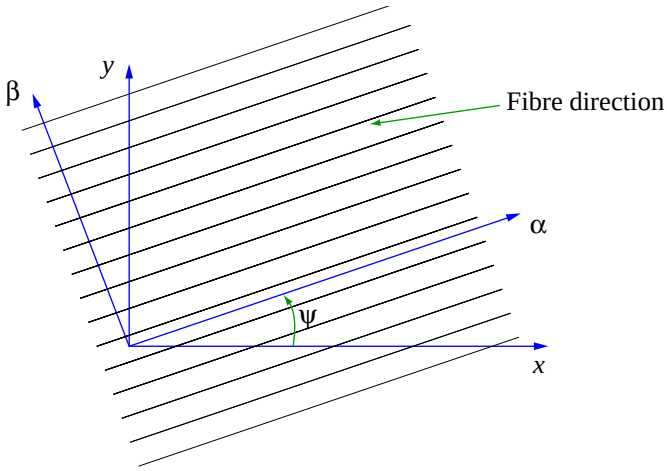


Sketch 1.1 Plate dimensions



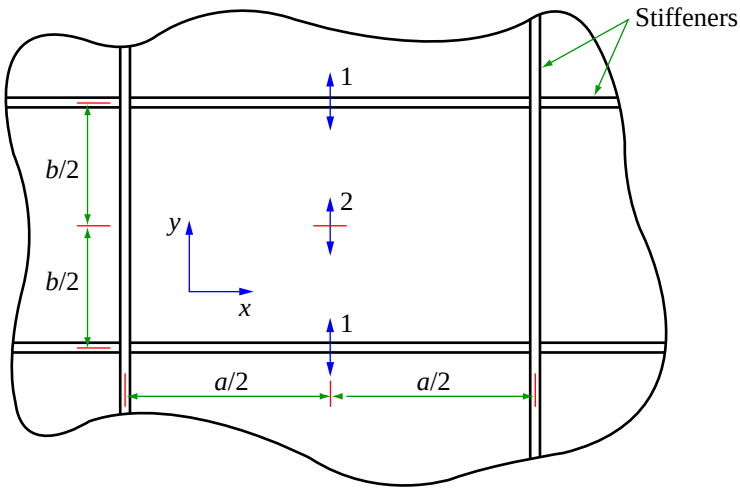
Sketch 1.2 Relationship between plate and layer axes

2. NOTES

2.1 General

This Data Item provides a means of estimating the r.m.s. surface strains in rectangular laminated skin panels subjected to random acoustic loading. The data are applicable to specially orthotropic plates (see Section 2.2) having principal axes of orthotropy parallel to the *x*- and *y*-axes. The data provided are particularly applicable to fibre reinforced composite laminates.

Because of the large number of lay-up configurations that may be used in laminated plates it is not possible to provide r.m.s. strain data in graphical form. Data are generated by a computer program with example input and output files contained in ESDUpac A8408.



Sketch 2.1 Strain locations

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The location, and direction, of the r.m.s. strains provided for skin panels under the action of acoustic loading is shown in Sketch 2.1. For curved plates, where b is the arc length of the plate, the strains provided are in the circumferential direction. For plates of normal construction, the critical strain location is usually position 1. However, if the plate edges are reinforced the critical strain location may be the centre of the plate.

From the analysis of test data, available at the time of the development of this Item, it was not possible to obtain a unique correlation of x-direction r.m.s. surface strains at the centre of the plate ($x = a/2$, $y = b/2$) for the different sets of test data. Therefore no data are provided for the estimation of x-direction strain at the plate centre.

2.2 Specially Orthotropic Laminated Plates

Specially orthotropic laminated plates are balanced laminates having layers of equal thickness, elastic properties and orientations symmetrically arranged about the plate central plane. The conditions for special orthotropy are detailed in ESDU 83035. In specially orthotropic plates, the in-plane and flexural stiffnesses are uncoupled so that the flexural load deformation relationship (used in determining S_o) is

$$[\mathbf{M}] = [\mathbf{D}]\ [\mathbf{K}], \tag{2.1}$$

which, in its expanded form, becomes

$$\begin{bmatrix} M_x \\ M_y \\ M_{xy} \end{bmatrix} = \begin{bmatrix} D_{11} & D_{12} & 0 \\ D_{21} & D_{22} & 0 \\ 0 & 0 & D_{33} \end{bmatrix} \begin{bmatrix} \partial^2 w/\partial x^2 \\ \partial^2 w/\partial y^2 \\ 2\partial^2 w/\partial x \partial y \end{bmatrix} \tag{2.2}$$

The **D**-matrix in Equation (2.2) is symmetric so that $D_{12} = D_{21}$.

In ESDU 82013 (Reference 6) the stacking sequence of layer angles to achieve specially orthotropic laminates is given for laminates with even and odd numbers of layers for both symmetric and anti-symmetric ply orientations about the central plane. In practice it is difficult to manufacture laminated plates that exactly conform to the conditions of special orthotropy, but many multilayered composite laminates approximate to those conditions which allow simple procedures to be used to estimate the response of plates under acoustic loading.

2.3 Method of Calculation

The r.m.s. surface stress is first calculated using the approximate relationship

$$S_{rms} = \left[\frac{\pi}{4\delta} f_n G_p(f_n)\right]^{1/2} S_o, \tag{2.3}$$

where S_o, the ratio of stress in the surface of the plate to the applied uniform static pressure on the plate, is derived within the computer program.

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