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The estimation of r.m.s. stress in skin panels with flexible stiffeners subjected to random acoustic loading

Associated software: ESDUpac A7314

Endorsed by
The Royal Aeronautical Society

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We are constantly striving to develop new work and review data already issued. Any comments arising out of your use of our data, or any suggestions for new topics or information that might lead to improvements, will help us to provide a better service.

THE PREPARATION OF THIS DATA ITEM

The work on this particular Item was monitored and guided by the Acoustic Data Fatigue Panel which first met in 1966 and now has the following membership:

Chairman
Prof. B.L. Clarkson — Institute of Sound and Vibration Research, University of Southampton

Vice-Chairman
Mr W.T. Kirkby — Royal Aircraft Establishment

Members
Mr D.C.G. Eaton — British Aircraft Corporation Ltd, Filton
Mr J.A. Hay — British Aircraft Corporation Ltd, Weybridge
Mr M.J.T. Smith — Rolls-Royce (1971) Ltd, Derby
Mr N.A. Townsend — Hawker Siddeley Aviation Ltd, Hatfield.

The construction and subsequent development of the Data Item were undertaken by

Mr A.G.R. Thomson — Executive – Environmental Projects
Mr R.F. Lambert — Environmental Projects Group.

Since 1970, Governments of NATO Nations have provided financial assistance through the Advisory Group for Aerospace Research and Development (AGARD) for revising and extending the data provided in Data Items on acoustic fatigue that were first issued by ESDU in 1966 and 1967. The Acoustic Fatigue Working Group (under the Chairmanship of Mr A.H. Hall, National Aeronautical Establishment, Canada) of the AGARD Structures and Materials Panel initiated and directed this additional work and appointed National Coordinators (see below) for each of the sponsoring Nations to provide basic data and to review AGARDographs as prepared by ESDU staff, monitored and guided by the Acoustic Fatigue Panel.

The National Coordinators who provided basic data and reviewed the publication of the results in AGARDograph form are:

Mr G. Bayerdörfer — Industrieanlagen-Betriebs GmbH, Germany
Maj.Gen. A.Griselli — Ministero della Difesa Aeronautica, Italy
Mr A.W. Kolb — Wright Patterson Air Force Base, USA
Dr G.M. Lindberg — National Aeronautical Establishment, Canada
Mr R. Loubet — Société Nationale Industrielle Aérospatiale, France
Mr F.F. Rudder — Acoustics and Vibration Associates, Inc., USA
Mr N.A. Townsend — Hawker Siddeley Aviation Ltd, UK.

The results of their work are published as AGARDograph 162, Parts 1 to 3 1972/3, on part of which this Data Item is based.

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THE ESTIMATION OF RMS STRESS IN SKIN PANELS WITH FLEXIBLE STIFFENERS SUBJECTED TO RANDOM ACOUSTIC LOADING

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THE ESTIMATION OF RMS STRESS IN SKIN PANELS WITH FLEXIBLE STIFFENERS SUBJECTED TO RANDOM ACOUSTIC LOADING

1. NOTATION

		SI	*British*
A_s	cross-sectional area of stiffener (see sketch 1.1)	m^2	in^2
a	length of longer side of plate	m	in
b	length of shorter side of plate	m	in
D	flexural rigidity of plate, $E_p t^3/\{12(1-\nu^2)\}$	N m	lbf in
E	Young's modulus	N/m^2	lbf/in^2
f	fundamental natural frequency of panel with edges fixed against rotation	Hz	Hz
f_{ref}	reference frequency of plate	Hz	Hz
$G_p(f)$	spectral density of acoustic pressure at frequency f	$(N/m^2)^2/Hz$	$(lbf/in^2)^2/Hz$
h	stiffener dimension defined in Sketch (1.1)	m	in
I	second moment of area of stiffener (without skin) about its neutral axis parallel to plate (see Sketch 1.1)	m^4	in^4
K'	stress parameter [for plate stresses $K' = K_n$ and for stiffener stress $K' = (E_s/E_p)\ (2h/t)K_s$]		
K_n	plate stress parameter		
K_s	stiffener stress parameter		
K_δ	damping ratio correction factor		
$L_{ps}(f)$	spectrum level of acoustic pressure at frequency f	dB	dB
p	uniform static pressure on plate	N/m^2	lbf/in^2
p_{rms}	root mean square fluctuating pressure	N/m^2	lbf/in^2
S_0	ratio of stress at specified plate or stiffener location to applied uniform static pressure on plate, $(6/\pi^2)\ (a/t)^2\ K'$		
S_{rms}	rms stress due to acoustic loading	N/m^2	lbf/in^2

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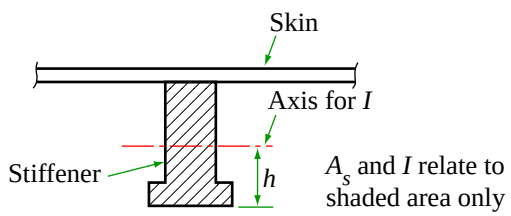
t	thickness of plate	m	in
δ	damping ratio in vibrating mode		
δ_{ref}	reference damping ratio (= 0.017)		
ν	Poisson's ratio for plate material		
ρ	density	Kg/m^3	*

Suffixes

n	1-5 denotes location of plate stress (see Sketch 2.1)
p	denotes plate
s	denotes stiffener

* A density value expressed in British units as pounds per cubic inch has to be divided by 386.4 before being used to calculate parameters defined in this Item. (A force of 1 lbf acting on a mass of 1 lb produces an acceleration of 386.4 in/s^2.) For example, if the material density is 0.097 lbf/in^3, the value used in the calculation should be 2.51×10^{-4} lb s^2/in^4.



Sketch 1.1 Stiffener geometric parameters

Both SI and British units are quoted but any coherent system of units may be used.

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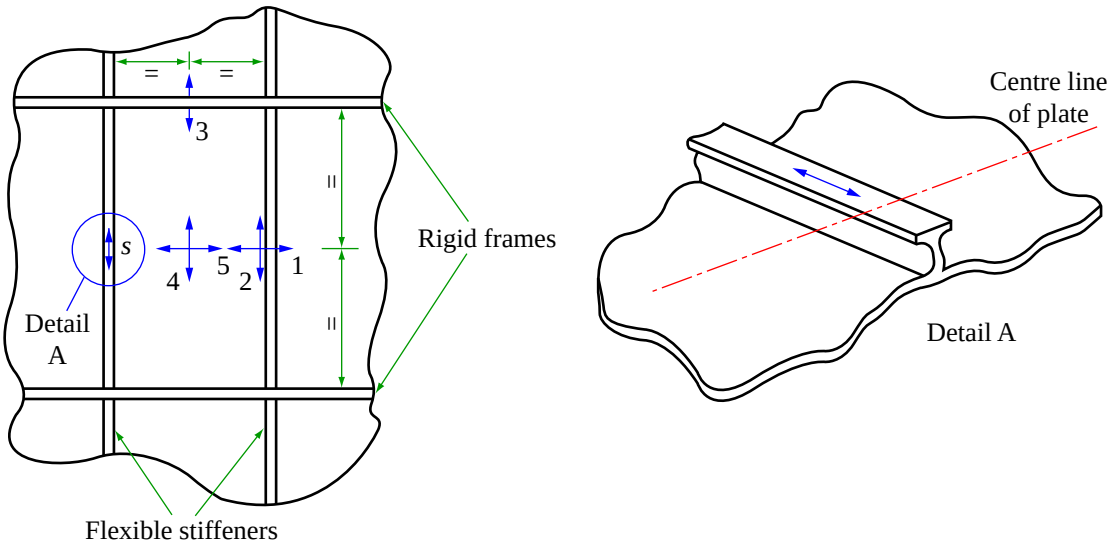
2. NOTES

This Data Item gives a method of estimating the rms stress in flat rectangular skin panels with flexible stiffeners under the action of random acoustic loading. The stress locations and direction of rms stress on the skin surface remote from the stiffeners (locations 1-5) and the stiffener free edge stress (location *s*), for which values are provided, are shown in Sketch 2.1.



Sketch 2.1 Stress locations

The rms stress for a stiffened panel subjected to random acoustic loading on one side is given approximately by the expression

$$S_{rms} = \left[\frac{\pi}{4\delta_{ref}} f\, G_p(f)\right]^{1/2} K_\delta S_0 , \tag{2.1}$$

when only the fundamental natural mode is excited by the noise. The ratio S_0 is a function of the stress parameter K' and the solution of Equation (2.1) is presented via nomographs in which K' is one of the parameters. The value of K' is obtained from values of K_n and K_s which are plotted against $E_s I/Db$ for a range of values of a/b in Figures 1-20 and 21-24 respectively. Each of these Figures is drawn for a particular value of $\rho_s A_s/(\rho_p bt)$ as detailed in the table below.

	Figure Nos. for stress parameters K_n and K_s			
stress location \ $\frac{\rho_s A_s}{\rho_p bt}$	0	1	2	3
1	1	2	3	4
2	5	6	7	8
3	9	10	11	12
4	13	14	15	16
5	17	18	19	20
s	21	22	23	24

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Figures 25 and 26 give nomographs for S_{rms}. The nomographs are entered at a value of $L_{ps}(f)$ [related to $G_p(f)$ – see Section 3.2], each quadrant being used in turn in the direction indicated through ranges of a/t, K' and f. Figure 26 is an extension of the stress range of Figure 25. The stress nomographs are drawn for a value of $\delta = 0.017$; S_{rms} for other values of δ is calculated using a correction factor K_δ which is plotted against δ in Figure 27. Guidance on values of δ for typical aircraft structures may be found in ESDU 73011.

For structures which have not been treated to increase their inherent damping, f should be taken as the undamped natural frequency.

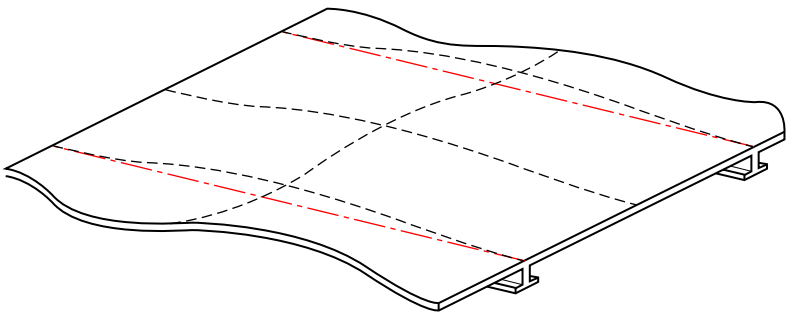
The use of a second moment of area of the stiffener (without skin) taken about its neutral axis parallel to the plate has been found to give closest correlation with limited test data. It is possible that in certain configurations the effective neutral axis could lie closer to the skin but as yet there is insufficient evidence to clarify this point.

For panels with riveted stiffeners the edge stresses may be used as the nominal rivet line values. In using these stresses to calculate a fatigue life care must be taken to ensure that fatigue data from similar structures are used so that geometric stress concentration factors are of the same order.

In Appendix A a computer program, based on the procedure of this Item and ESDU 73013, is described which calculates the fundamental natural frequency and stress response to acoustic loading of panels with flexible stiffeners. The program, referred to as ESDUpac A7314, is provided with this Item.

2.1 Assumptions Made in Derivation of Figures

In obtaining the values of K_n and K_s presented in Figures 1-24 the panels were assumed to be built-up from plates fully fixed on their shorter sides, and attached to flexible stiffeners along their longer sides. The assumed deflected shape is shown in Sketch 2.2. At plate locations 1 and 2 the value of K_n, for plates having a high aspect ratio and very flexible stiffeners, reduces to zero and then increases as $E_s I/Db$ increases. This is due to the change in sign of S_0 as the stiffness of the plate relative to that of the stiffener is increased.



Sketch 2.2 Assumed deflected shape

The number of individual plates in the panel, between each pair of rigid supports or stiff frames, was taken to be sufficiently great for the centre plate and associated stiffeners to be unaffected by the number of plates in the panel. The pressure is assumed to be uniform and in phase over the whole of the panel and the spectrum level of the acoustic pressure is taken to be constant over the range of frequencies close to the fundamental natural frequency of the panel.

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In the derivation of the nomograph it is assumed that the plate bending stress is within the linear region where it is directly proportional to the normal pressure, that is p/E_p less than about 20 $(t/b)^4$ (see ESDU 71013). Also the value of ν is taken to be 0.3; use of this value gives sufficiently accurate stresses for all common structural metallic materials.

3. CALCULATION PROCEDURE

3.1 Graphical Procedure for Estimating S_{rms}

(i) Estimate the reference frequency f_{ref} of the panel using ESDU 73013. For the purpose of calculating stress this reference frequency may be taken as the fundamental natural frequency.

(ii) Obtain the value of spectrum level of acoustic pressure $L_{ps}(f)$ at the calculated frequency. If only the band pressure level is known, it is first corrected to pressure spectrum level (unit bandwidth) using ESDU 66016. The reference pressure for sound pressure level is 20 μN/m^2.

(iii) Calculate the parameters a/b, $E_s I/Db$ and $\rho_s A_s/(\rho_p bt)$ and from Figures 1-20 obtain the appropriate value of plate K'.

(iv) For stiffener S_{rms} calculate the parameter $(E_s/E_p)\,(2h/t)$ and multiply K_s by the parameter to obtain the required value of K'.

(v) Calculate the parameter a/t and read the value of S_{rms} from Figure 25 or 26. The nomographs are entered at a value of $L_{ps}(f)$, each quadrant being used in turn in the direction indicated through ranges of a/t, K and f.

(vi) For values of δ other than 0.017, factor the estimated value of S_{rms} by K_δ obtained from Figure 27.

3.2 Loading

Within the nomograph the spectrum sound pressure level is converted into the spectral density of acoustic pressure. The spectrum sound pressure level is converted into the root mean square fluctuating pressure in units of (N/m)^2/Hz (see expression below or ESDU 66018) and then squared giving a value in units of (N/m^2)^2/Hz^2. Since unit bandwidth is used this is numerically equal to the spectral density of acoustic pressure $G_p(f)$ in units of (N/m^2)^2/Hz.

When p_{rms} is in SI units the spectrum sound pressure level is given by

$$L_{ps}(f) = 20\,(\log_{10} p_{rms} + 4.70)\,,$$

and for p_{rms} in British units of lbf/in^2

$$L_{ps}(f) = 20\,(\log_{10} p_{rms} + 8.54)\,.$$

4. COMPARISON WITH MEASURED DATA

Figure 28 shows a comparison of estimated and measured stresses in flat stiffened panels using the calculated frequency and assuming $\delta = 0.017$.

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5. DERIVATION AND REFERENCES

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6. EXAMPLE

A plate that is an element of an integrally-machined panel is subjected to jet noise on one side. It is required to estimate the plate surface stresses at the centre and edges on the plate centre line, and the stiffener free-edge stress at the centre of the longer plate side.

The variation of sound pressure level over a range of frequencies is given in the table, sound pressure levels being 1/3 octave band levels.

Sound pressure level (dB)	151	155	156	155	153
Frequency (Hz)	50	100	200	300	500

The panel is made up from stiffeners and uniform plates having the following dimensions and properties:

$$a = 600 \text{ mm}, \quad b = 120 \text{ mm}, \quad t = 0.8 \text{ mm},$$
$$A_s = 43.3 \text{ mm}^2, \quad h = 8.1 \text{ mm}, \quad I = 950 \text{ mm}^4,$$
$$E_p = E_s = 70\,000 \text{ MN/m}^2, \quad \rho_p = \rho_s = 2770 \text{ kg/m}^3,$$
$$\nu = 0.3, \quad \delta = 0.015.$$

From ESDU 73013 the fundamental natural frequency of the panel is 124 Hz.

By interpolation from the table the 1/3 octave band pressure level at 124 Hz is 155.9 dB.

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From ESDU 66016,

$$L_{ps}(f) = 155.9 - 14.8 = 141.1 \text{ dB}.$$

Now

$$D = \frac{70\,000 \times 10^6 \times (0.8 \times 10^{-3})^3}{12(1-0.3^2)} = 3.28 \text{ N m},$$

$$\frac{a}{b} = \frac{600}{120} = 5,$$

$$\frac{E_s I}{Db} = \frac{70\,000 \times 10^6 \times 950 \times 10^{-12}}{3.28 \times 120 \times 10^{-3}} = 169$$

and

$$\frac{\rho_s A_s}{\rho_p bt} = \frac{2770 \times 43.3 \times 10^{-6}}{2770 \times 120 \times 10^{-3} \times 0.8 \times 10^{-3}} = 0.451.$$

Also

$$\frac{a}{t} = \frac{600}{0.8} = 750, \quad \frac{E_s}{E_p} = 1 \text{ and } \frac{2h}{t} = \frac{2 \times 8.1}{0.8} = 20.8.$$

Hence

$$\left(\frac{E_s}{E_p}\right)\left(\frac{2h}{t}\right) = 20.8.$$

From Figure 27, for $\delta = 0.015$, $K_\delta = 1.06$.

Plate rms stresses

From Figures 1-20 the values of K' are read for $\rho_s A_s/\rho_p bt = 0$ and 1 and by linear interpolation the values of K' for $\rho_s A_s/(\rho_p bt) = 0.451$ are found. From Figure 26, entering the nomograph at 141.1 dB, the values of plate rms stresses are obtained as shown in the table.

	Stress parameter K'			S_{rms}	MN/m^2
Stress location	$\frac{\rho_s A_s}{\rho_p bt} = 0$	$\frac{\rho_s A_s}{\rho_p bt} = 1$	$\frac{\rho_s A_s}{\rho_p bt} = 0.451$	$\delta = 0.017$	$\delta = 0.015$
1	0.0264	0.0135	0.0206	121	128
2	0.0053	0.0009	0.0033	19.4	20.5
3	0.0040	0.0037	0.0039	22.9	24.3
4	0.0122	0.0080	0.0103	60.5	64.1
5	0.0285	0.0156	0.0227	133	141

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