

ESTIMATION OF RMS STRESS IN INTERNAL PLATES OF A BOX STRUCTURE SUBJECTED TO RANDOM ACOUSTIC LOADING

1. NOTATION

a	spar pitch	m	in
b	rib pitch	m	in
d	depth of box	m	in
E	Young's modulus	N/m ²	lbf/in ²
f	natural frequency of response	Hz	Hz
$G_p(f)$	spectral density of external acoustic pressure at frequency f	(N/m ²) ² /Hz	(lbf/in ²) ² /Hz
K_n	bending 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_{rms}	root mean square stress due to acoustic loading	N/m ²	lbf/in ²
t	plate thickness	m	in
δ	damping ratio in vibrating mode		
δ_{ref}	reference damping ratio (= 0.017)		
ν	Poisson's ratio for plate material		
<i>Suffixes</i>			
n	1-3 denotes location of plate stress (see Sketch 3.1)		
r	denotes rib		
s	denotes spar		

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2. INTRODUCTION

The first step in predicting the stress response to acoustic loading is to estimate the predominant frequency of vibration. For structures in which skin and rib plates are coupled this may be done using the procedure outlined in Item No. 74025. The conditions for coupled vibratory response of skin and rib plates are discussed in Section 2 of Item No. 74025. For structures where skin and rib plates are unlikely to be coupled, the response frequency should be estimated for each individual plate of the box separately; the stress response is then estimated for each plate using its own response frequency. Estimates of plate natural frequencies may be obtained from Item Nos. 72003, 72016, 73013, 75030 and 87002.

In box structures where skin and rib plates are coupled, skin and rib rms stresses at similar plate locations are of the same order. For uncoupled mode conditions, where ribs have relatively less bending stiffness than skins, the critical stress is likely to be that in the rib-flange radius, and when ribs are stiffer than skin plates the critical stress is likely to be in the skin at the rib-joint locations.

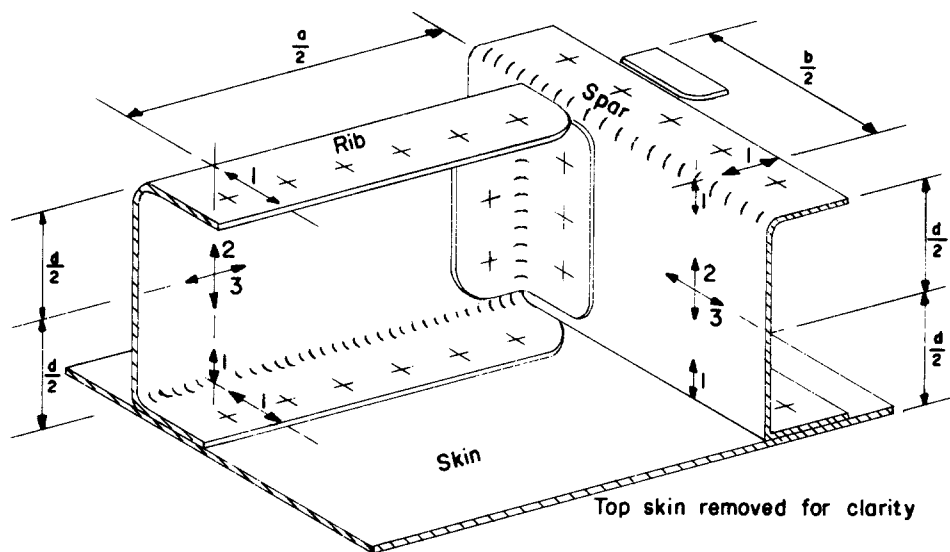
Methods for estimation of rms stress in single plates or panels, subjected to acoustic loading, are presented in Item Nos 72005 and 73014. It should be noted that for plates that are part of a box structure, subjected to acoustic loading on one side only, the stresses predicted by the above Data Items should be multiplied by 1/3. This factor is to allow for the mechanical coupling provided by the ribs which results in the exciting energy being absorbed by two vibrating skins and interconnecting ribs.

For box structures, vibrating in a mode in which skin and rib plates are coupled, it is possible to obtain rib stresses by applying a suitable theoretical factor to the skin stress. However, it has been found that, for the limited test data available, the method suggested in this Data Item gives closer agreement between measured and estimated stresses than the coupled response method.

3. NOTES

3.1 Data Presented

This Data Item gives a method of estimating rms bending stresses in internal plates of box structures under the action of random acoustic loading. The boxes are assumed to be constructed from flat panels that are initially unstressed. The locations at which rms stresses are predicted are the rib and spar centres, and the edges and flanges adjoining the skin plates. The rib edge and flange stresses are at the middle of the plate side adjoining the skin and for these stresses it is implicit that the adjoining skin and rib plates are vibrating in a coupled response mode. The locations and directions in which rms stresses are presented are shown in Sketch 3.1.



Sketch 3.1

The rms stresses for rib and spar-web plates of a box structure that is subjected to random acoustic loading on one side are given approximately by the expression

$$S_{rms} = 1/3 \left[\frac{\pi}{4\delta_{ref}} f G_p(f) \right]^{1/2} \left(\frac{d}{t} \right)^2 K_n K_\delta,$$

when only one natural frequency is excited by the noise.

In Figure 1, values of K_n , the bending stress parameter, are plotted against a/d and b/d . For rib stresses, values of K_n are read corresponding to the rib aspect ratio, a/d , and for spar stresses values of K_n are read for the aspect ratio, b/d .

Figures 2 and 3 give nomographs for S_{rms} . Figure 3 is an extension of the rms stress range of Figure 2. The stress nomographs are drawn for the reference damping ratio, $\delta_{ref} = 0.017$; S_{rms} for other values of δ is obtained by multiplying the value estimated using δ_{ref} by K_δ which is plotted against δ in Figure 4. Guidance on values of δ for typical aircraft structures may be found in Item No. 73011.

3.2 Assumptions in the Analysis

It is assumed that each of the internal plates of a box structure may be considered in isolation under the action of the acoustic loading applied to the skin plate adjoining the internal plate under consideration.

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 less than about $20(t/d)^4$ (see Item No. 71013). In calculating K_n the value of ν was assumed to be 0.3; use of this value gives a sufficiently accurate stress for all common structural metallic materials.

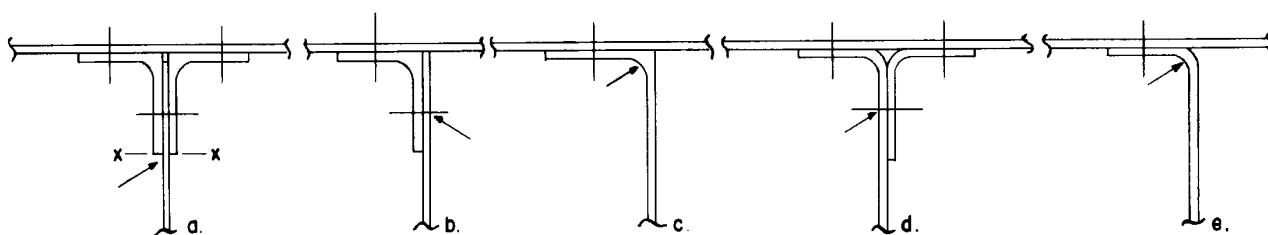
The pressure is assumed to be uniform and in-phase over the whole of each individual skin plate and the spectrum level of acoustic pressure is assumed to be constant over the range of frequencies close to the natural frequency of response of the box structure. If the response frequency of the structure is not known, for conventional aircraft structures without special damping treatment the first natural frequency obtained

from Item No. 74025 should be used.

When box structures do not vibrate in a mode in which skin and rib plates are coupled, the response frequencies of the rib and skin plates may be such that there is a significant difference between the spectral density of acoustic pressure at the two frequencies. This condition may occur, for example, in boxes with deep ribs. Estimated rms stresses, for such cases, should be used with caution when predicting fatigue life. There are insufficient test data for this type of box structure to provide guidance for these cases.

Due to mechanical coupling between skin plates, provided by the ribs and spars, it has generally been found that, for box structures subjected to noise on one side only, the rms stress response on the internal plate edge and flange adjoining the skin plate remote from the excitation agrees closely with that obtained from those adjoining the skin plate directly excited by the noise. For box structures subjected to noise on both skin plates, such as aircraft fin boxes, it is recommended that the calculated value of S_{rms} , obtained from this Data Item, should be multiplied by 1.4.

The rib, or spar, edge stresses obtained from this Data Item are nominal values in the plain material adjacent to the bend-radius or joint. The appropriate stress to be used in estimating fatigue life, from Item Nos 72015 or 73010 (or other endurance data), is dependent on the detail design of the joint used. Typical riveted skin/rib joints are shown in Sketch 3.2. Likely critical regions on the ribs for these joints under acoustic loading are Section xx for *a*, the rivet holes for *b* and *d* and the rib flange bend radius for *c* and *e*; these locations are arrowed in Sketch 3.2.



Sketch 3.2

This Data Item may be used to obtain first approximations to the rms stresses in box structures with stiffened skin plates. In these cases an effective thickness is used which should be that necessary to give the same frequency as the stiffened plate.

4. CALCULATION PROCEDURE

4.1 Procedure for Estimating S_{rms}

- (i) If the response frequency is not known, estimate the lowest natural frequency of the box using Item No. 74025.
- (ii) Obtain the value of spectrum level of acoustic pressure $L_{ps}(f)$ at the response frequency. If only the band pressure level is known, it is first corrected to pressure spectrum level (unit bandwidth) using Item No. 66016. The reference pressure for sound pressure level is 20 vN/m^2 .
- (iii) For each rib plate and spar plate to be considered calculate the parameters a/d and b/d respectively and, from Figure 1, read the appropriate values of K_n .
- (iv) Calculate the plate parameters d/t_r and d/t_s and, for each plate location and stress direction, read the values of S_{rms} from Figures 2 or 3. The nomographs are entered at a value of $L_{ps}(f)$, each

quadrant being used in turn in the direction indicated through ranges of d/t , K_n and f .

- (v) For values of δ other than 0.017, multiply the estimated value of S_{rms} by K_δ obtained from Figure 4.

4.2 The 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 $(\text{N/m}^2)/\text{Hz}$ (see expression below or Item No. 66018) and then squared giving a value in units of $(\text{N/m}^2)^2/\text{Hz}^2$. Since unit bandwidth is used this is numerically equal to the spectral density of acoustic pressure $G_p(f)$ in units of $(\text{N/m}^2)/\text{Hz}$.

Using SI units,

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

If $L_{ps}(f)$ is required in British units of $(\text{lbf/in}^2)^2/\text{Hz}$ it is given by

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

5. COMPARISON WITH MEASURED DATA

Figure 5 shows a comparison of estimated and measured rms stresses in internal plates of box structures using the lowest natural frequency for each box calculated by the method presented in Item No. 74025. In calculating these stresses the damping ratio was assumed to be δ_{ref} ($=0.017$). In Figure 6 a similar comparison of estimated and measured stresses is presented, the estimated stress being obtained using the measured plate response frequency and, where available, the measured damping ratio for the box structures. All boxes considered are idealised structures, i.e. without cutouts or stiffeners between ribs and spars.

6. DERIVATION

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