ACOUSTICALLY INDUCED VIBRATION OF PLATFORM MOUNTED EQUIPMENT CONTAINING PRINTED CIRCUIT BOARDS

J.N. Pinder[1], D.C.G. Eaton[2]

[1]Institute of Sound and Vibration Research Consultancy Services, University of Southampton, U. K.
[2]ESTEC, Noordwijk, Holland

ABSTRACT

Problems have been experienced during development and qualification testing at unit level with equipments containing printed circuit boards (PCB's). This has led to concern that such testing can be unduly severe when compared to the response behaviour observed at system level. The work described in this paper demonstrates that unit level tests are in fact likely to be unduly severe in some frequency regions and provides an insight into design and test guidance which it is intended to introduce into ESA's Structural Acoustics Design Manual. The paper outlines such features as: the insensitivity of the equipment box to direct acoustic excitation; the response behaviour of the platform and the mounted equipments to acoustic excitation; a comparison between the findings of the acoustic tests and responses induced by unit level mechanical vibration testing. Supporting analytical investigations using finite element and statistical energy analysis are outlined.

Keywords: vibroacoustic response testing, equipment box mechanical design, spacecraft panel vibration.

1. INTRODUCTION

It is not economical or often not even feasible to subject all spacecraft components to full-scale acoustic-field testing for the launch environment, in which the component is mounted to a structure dynamically similar to the spacecraft. Component random vibration testing is therefore normally performed with the intention that the vibration power fed into the component is, ideally, the same as when the component is installed for a spacecraft acoustic test. Realistically, it is recognised that the tests cannot in general be exactly equivalent, due primarily to the difference in mounting impedance between the component and the spacecraft or the shaker. The flexibility of the spacecraft panels causes rocking and other complex motions to be imposed on the component base as it responds to the acoustic field, the component being primarily excited via its mountings on the spacecraft rather than directly by the acoustic field.

The equivalence of vibration and acoustic testing has been long considered and investigated and certain procedures have been used. These either derive fixed or 'base' excitation levels for component test specifications or a procedure may be specified to derive the test levels from available data arising from an acoustic test which may use a dummy or preliminary form of the component.

The aim of this paper is to present the results of experiments to determine typical ranges of component response which arise from installation and data assessment variations. The experiments were performed as acoustic-field tests, with components mounted on a panel. In addition, vibration tests were performed to determine the degree of 'overtest' which occurs when the excitation is by unit level shaker tests.

It is intended that conclusions drawn from these tests be included in the ESA/ESTEC Structural Acoustics Design Manual [Ref.1] in the form of guidelines for designers.

SCOPE OF TESTS

2.1 Equipment Tested

Three electronic equipment boxes were tested (see Table 1). In each box, one printed circuit board (p.c.b.) was monitored using accelerometers. A strain gauge was also installed on the instrumented p.c.b. in box 3. The relative motion between some p.c.b. mounted components and the p.c.b. was also measured, using a laser velocimeter (LDV).

Almost all the tests were performed for both acoustic and shaker excitation. Only mechanical response was measured, without any functionality testing.

2.2 Acoustic Tests

The equipment boxes were mounted on a honeycomb panel which was based on an Olympus panel (see Figure 1). All boxes were tested mounted at location F, first as the sole mounted mass and then with five dummy boxes (see Table 1) at locations A, B, C, D and E.

In addition, box 3 was tested, mounted in isolation, at locations A, B and C. Box 3 has also been tested on an OTS spacecraft platform.

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Table 1. Equipment Boxes Tested

Box No.	Total Mass (kg)	P.C.B. (mm × mm)	No. transducers on P.C.B.
1	1.0	ca. 130 × 210	3
2	2.0	ca. 90 × 120	3
3	2.45	ca. 160 × 200	6
Dummy	2.5	-	-

2.3 Vibration Tests

The boxes were mounted directly to a shaker fixture and first excited in the direction perpendicular to the plane of mounting onto the honeycomb panel used in the acoustic tests. In the cases of boxes 1 and 3, this direction was perpendicular to the plane of the instrumented p.c.b., but in box 2 this was parallel to the plane of the instrumented p.c.b.

The boxes were also excited in a direction parallel to the plane of the honeycomb panel. In the case of box 2, this gave the highest p.c.b. response.

Referring now to the plane of the p.c.b. rather than to the plane of the honeycomb panel, the total of six tests thus covered both the direction perpendicular to the plane of the p.c.b. and one of the two perpendicular axes parallel to the plane of the p.c.b. From the two latter directions, that expected to cause most relative response between the p.c.b. mounted components and the p.c.b. was chosen.

3. THE DERIVATION OF COMPONENT RANDOM VIBRATION TEST LEVELS

Vibration test levels can be derived from acoustic test experience by application of several methods, including:

(a) Enveloping or bounding response data
(b) Statistical analysis of plentiful response data
(c) Fitting simple linear curves through measured data.

All the results of these analyses can be subject to safety factors to give finally the vibration test level.

Method (a) is recognised to give large values of overtest. It has been concluded [Ref. 2] that a resulting overtest factor as high as 25 for vibrational response energy is acceptable because it has historically produced reliable equipment and by implication allows for the variations in response which will arise from design changes and modification for future applications, from repeated testing and from variation during spacecraft development of installation factors during the design phase such as change in mass loading or location.

Reference [2] refers to bounding of acoustic test response spectra in accordance with MIL-STD 1540 procedures. However, the current version B of that standard does not mention bounding explicitly, but requires that if less than three data samples are available, a minimum margin of 3 dB is applied to account for variability of the environment.

For efficient design, a minimum overtest or safety factor is required, so method (a) is not the most desirable. In an application of method (b), statistical analysis of several projects has been performed to derive a proposed ESA standard for unit level tests [Ref. 3].

A draft ESA standard for unit level test verification was issued in 1988 [Ref. 4]. The levels proposed for equipment of mass < 50 kg for hard mounting on a honeycomb panel are shown in Appendix 1. The levels shown in section (a) of the panel in Appendix 1 have been assumed to be appropriate for the three equipment boxes tested.

4. EXPERIMENTAL SYSTEMS

The acoustic testing was performed in the ISVR small reverberation chamber (131 m^3). The noise levels were about 103 dB OASPL and the measured response levels were normalised to Ariane 4 qualification levels assuming a smooth narrow band spectrum shape. Thus linearity was assumed, so the Ariane 4 spectrum shape was not attempted to be met in the test chamber.

Panel response levels were measured near the four corners of the box base and also more remote from the box in some cases.

The vibration tests were performed on a Derritron type VP 85 shaker and excitation levels measured on the fixture table beside the four box corners. Again, the levels were normalised to the qualification test levels (as given in Appendix 1) assuming linearity and the spectrum was shaped to be as smooth as possible rather than the specified shape.

The measurement transducers used are given in Table 2 and Figure 2 shows the layout in Box 3.

Table 2. Response Transducers

Location	Type	Mass (gm) (ex. cable)
Box feet/panel	B & K 4375 accel.	2.4
P.C.B.	B & K 4374 accel.	0.65
P.C.B. (Box 3)	Philips semi-cond. strain gauge	-
P.C.B. & compts.	LDV (ISVR)	-

The response signals were processed using a Brüel and Kjaer 2032 dual channel FFT analyser and post-processed by ISVR software.

5. RESPONSE OF P.C.B. TO ACOUSTIC TESTING

5.1 Excitation Path in Acoustic Tests

Figure 3 shows vibration of the p.c.b. in box 3, both fixed to and separated from (but close to) its OTS platform. It is clear that the dominant excitation path is via the platform mounting [Ref. 5].

5.2 Response Behaviour of Platform

The structure-borne excitation of the equipment results in a highly selective frequency response characteristic of the p.c.b., since the platform's characteristics act as an intermediate filter between the smooth acoustic excitation spectrum and the dynamic characteristics of the equipment. Figure 4 shows the averaged normalised response of the test panel of Figure 1, measured close to the mounting points of box 3 (normalised to Ariane 4 acoustic test qualification level).

Figure 5 shows the mode shape of the panel with box 3 installed, measured using the LDV. It has been concluded [Ref. 6] that the effect of the equipment is mostly a mass or inertial loading effect rather than local stiffening. Not only are the displacement contours seen to be locally influenced only slightly by the presence of the boxes but also predictions using FEA which included only mass effects gave good agreement with measured natural frequencies and mode shapes.

The applicability of SEA to the prediction of the response of this test panel has been investigated [Ref.6]. It was concluded that the influence of the equipments could not be assessed by treating them as subsystems due to difficulty in measuring coupling loss factors. Response at the equipment mounting was best predicted based on the bare panel response, without including the equipment masses as smeared mass in the platform motion estimate. The combined impedance factor, given in [Ref. 1], is then applied:

$$a_b^2(t) = a_p^2(t) \left| \frac{<z_p>}{<z>_p + z_b} \right|^2 \qquad (5.2.1)$$

where a_b = equipment acceleration
a_p = platform acceleration (spatially averaged)
$<z_p>$ = average point impedance at equipment mounting position
z_b = point impedance for the equipment mounting

It was found that this relationship underpredicted equipment mounting response.

5.3 Response Behaviour of Mounted Equipments

Figure 6 shows the response of box 3 p.c.b. normalised as for Figure 4. Both acceleation and strain levels are dominated by response within a small frequency range around 440 Hz, where a mode of the p.c.b. was identified by interpolating from a grid of displacement measured using the LDV.

The relative motion between the p.c.b. and its mounted components was of concern as this can cause mechanical failure of attachment legs. The small components require non-contacting transducers, so the LDV was used to measure the transfer function between component and p.c.b.. During mechanical vibration testing, transfer function moduli mostly lay in the range of about 0.5 to 2 but at high frequencies and under acoustic excitation, signal/noise levels were generally too low (LDV developments are soon expected to allow more sensitive and more convenient measurement). The components monitored were I.C. chips (dual-in-line through-soldered), and T.O.5 top-hat types) and flat two-wire mounted upright components.

6. OVERTEST MEASURED DURING MECHANICAL VIBRATION TEST

In Figure 7, the ratios between the shaker test response and the acoustic test response (the 'overtest') are shown when boxes 1 and 3 are fixed at location F. The response levels are of acceleration averaged over several locations. The effect of mass loading the panel is shown when the five dummy boxes are added in each case.

If the shaker test levels are derived from the panel motion beside the equipment mountings, the overtest is generally reduced. If only one measurement instead of the average of four locations is used, the range of overtest increases.

For box 3, the extra effect due to changing the location is shown in Figure 8. The corresponding values for strain are shown in Figure 9.

7. CONCLUSIONS

An extensive investigation into vibro-acoustic response of electronics equipment boxes has been performed, to allow guidelines for mechanical design to be developed. The main conclusions reached are:

(i) Excitation is normally predominantly structure-borne resulting in equipment internal response being very frequency selective. Ratios of power spectral density between p.c.b. response and excitation on the panel beside the equipment reached up to 100 at p.c.b. resonant frequencies.

(ii) The combined impedance factor, estimated from measured individual impedances, underestimates equipment foot excitation levels when applied to the measured averaged panel response. This could be compensated for to some extent at the design stage by applying this factor to the predicted spatially averaged response of the bare panel rather than to the predicted averaged response of the loaded panel, where the predictions are made using S.e.A.

(iii) If the equipment loading is represented by its smeared mass, the spatially averaged level is underestimated, and the predicted level was found to be representative of the level at the equipment mounting locations.

(iv) Small components were not found to have vibration application factors relative to p.c.b. motion greater than about $\times$ 2.

(v) Shaker tests to ESA PSS draft levels can give values of overtest of about 30 based on power ratio at resonant frequencies.

(vi) Variations in acoustic test response due to location of the equipment and mass loading of the platform caused the range of the overtest factor to increase to about 35.

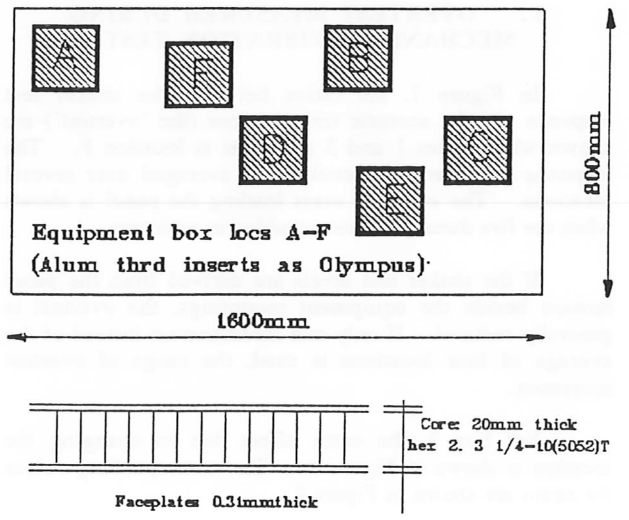

Figure 1. Acoustic test panel.

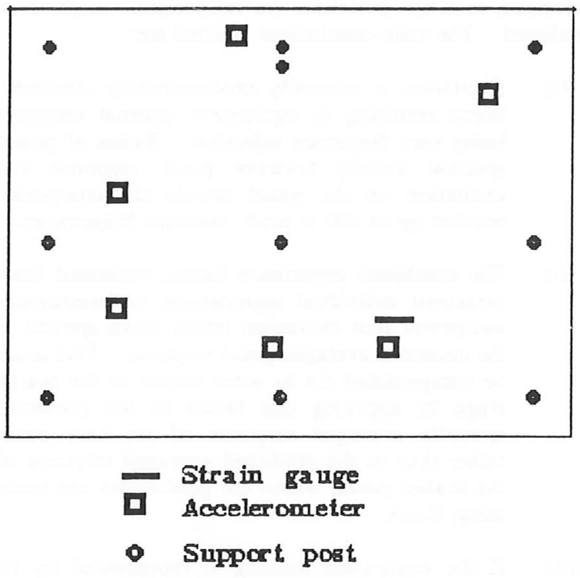

Figure 2. Box 3 p.c.b. layout.

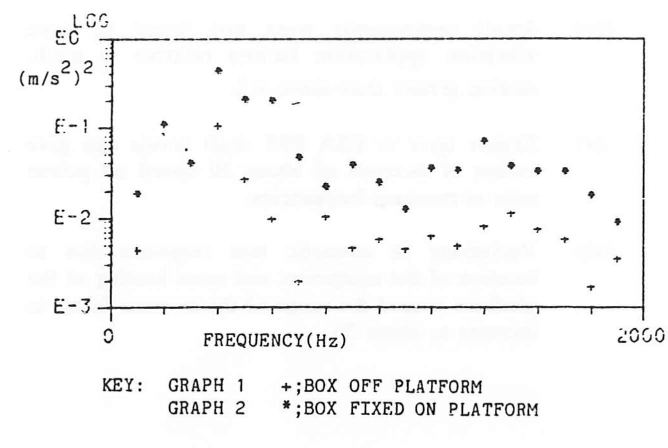

Figure 3. Excitation of Box 3 p.c.b.

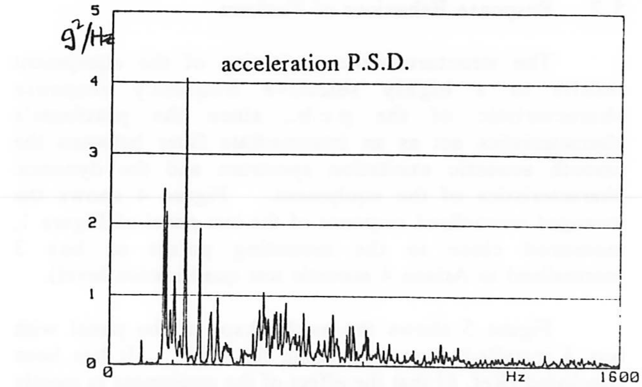

Figure 4. Averaged panel response near Box 3

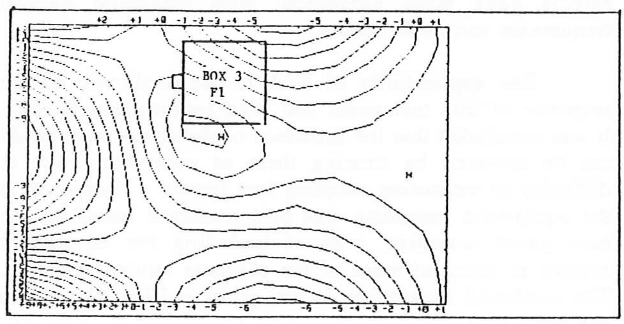

Figure 5. Mode shape of test panel at 240 Hz.

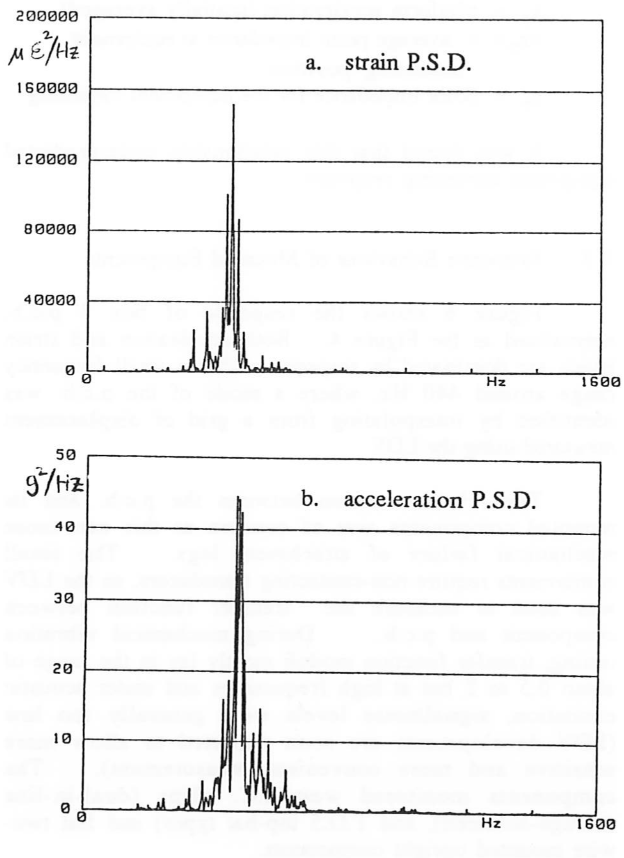

Figure 6. Response of Box 3 p.c.b. at location F.

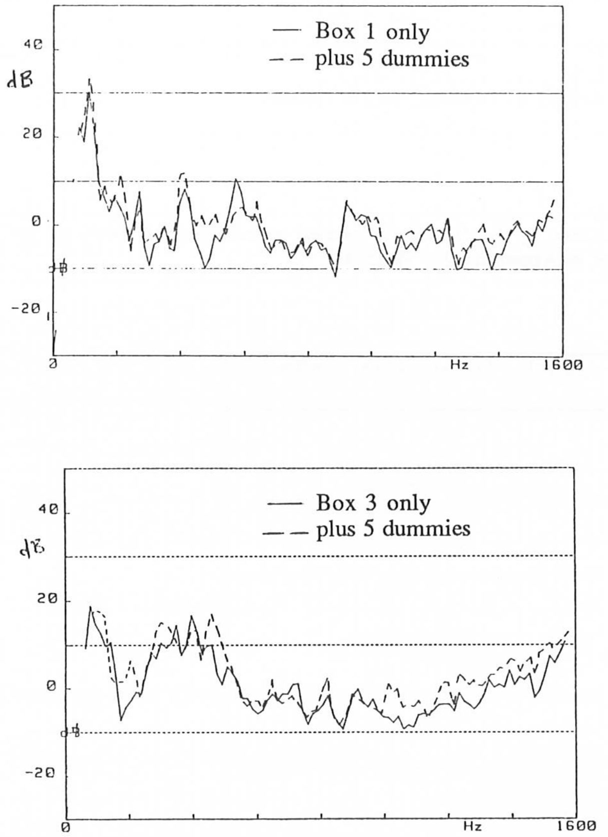

Figure 7. Overtest spectra at location F.

acceleration $\left[\frac{\text{P.S.D. of p.c.b. (shaker)}}{\text{P.S.D. of p.c.b. (acoustic)}}\right]$

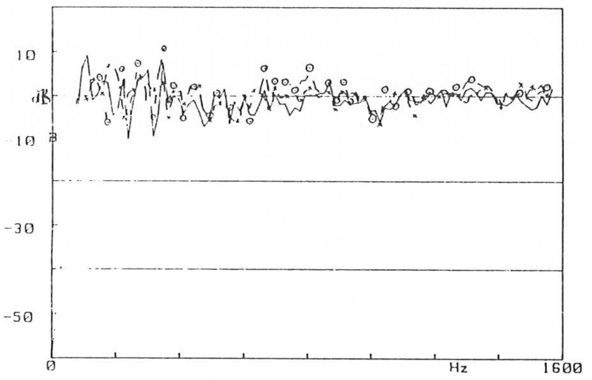

Figure 8. Range in overtest for Box 3 over locations A,B,C relative to location F (acceleration.

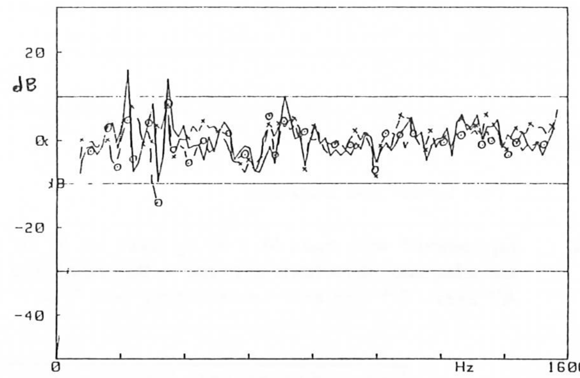

Figure 9. Range in overtest for Box 3 over locations A,B,C relative to location F (strain).

ACKNOWLEDGEMENTS

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APPENDIX 1
EXTRACT FROM ESA PSS-02-301 DRAFT ISSUE (MAY 1988)

4.2.5.3 Test Levels and Duration:

(a) Equipment* with mass M ≤ 50 kg (take for M the rigid part driven by the fixations) located on honeycomb panel (if not, use adequate corrections to come to this case) (see justification in Appendix 2). [Ref. 4]
All axes - 2.5 min/axis - no notching (see 7.14.1) [Ref. 4]

(a) Equipment located on "external" panel (1) or with unknown location		
vertical (2)	20-100 Hz	+ 3 dB/octave
	100-400 Hz	PSD (M kg) = 0.05 g^2/Hz) * $\frac{M + 20\ kg}{M + 1\ kg}$
	400-2000 Hz	-3 dB/octave
lateral (2)	20-100 Hz	+ 3 dB/octave
	100-200 Hz	PSD (M kg) = 0.05 g^2/Hz) * $\frac{M + 20\ kg}{M + 1\ kg}$
	200-2000 Hz	-4 dB/octave
(1) panel directly excited by payload acoustic environment (2) equipment vertical axis = perpendicular to fixation plane lateral axis = parallel to fixation plane		
(b) Equipment not located on "external" panel (1)		
	20-100 Hz	+ 3 dB/octave
	100-200 Hz	PSD (M kg) = 0.05 g^2/Hz) * $\frac{M + 20\ kg}{M + 1\ kg}$
	200-2000 Hz	-4 dB/octave

*exclude apogee motors, tanks, batteries.