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TECHNICAL REPORT

colour inside

Environmental conditions – Vibration and shock of electrotechnical equipment – Part 2: Equipment transported in fixed wing jet aircraft

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

ENVIRONMENTAL CONDITIONS – VIBRATION AND SHOCK OF ELECTROTECHNICAL EQUIPMENT –

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FOREWORD

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IEC/TR 62131-2, which is a technical report, has been prepared by IEC technical committee 104: Environmental conditions, classification and methods of test.

The text of this technical report is based on the following documents:

Enquiry draft	Report on voting
104/507/DTR	104/536/RVC

Full information on the voting for the approval of this technical report can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all the parts in the IEC 62131 series, under the general title *Environmental conditions – Vibration and shock of electrotechnical equipment*, can be found on the IEC website.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- reconfirmed,
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A bilingual version of this standard may be issued at a later date.

IMPORTANT – The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

ENVIRONMENTAL CONDITIONS – VIBRATION AND SHOCK OF ELECTROTECHNICAL EQUIPMENT –

Part 2: Equipment transported in fixed wing jet aircraft

1 Scope

IEC/TR 62131-2, which is a technical report, reviews the available dynamic data relating to electrotechnical equipment transported in fixed wing jet transport aircraft. The intent is that from all the available data an environmental description will be generated and compared to that set out in IEC 60721.

For each of the sources identified the quality of the data is reviewed and checked for self consistency. The process used to undertake this check of data quality and that used to intrinsically categorize the various data sources is set out in IEC/TR 62131-1.

This technical report primarily addresses data extracted from a number of different sources for which reasonable confidence exist as to their quality and validity. The report also presents data for which the quality and validity cannot realistically be reviewed. These data are included to facilitate validation of information from other sources. The report clearly indicates when it utilizes information in this latter category.

This technical report addresses data from several different transport aircraft[1]. Although one of these aircraft is no longer used commercially, data from it are included to facilitate validation of information from other sources.

Relatively little of the data reviewed has been made available in electronic form. To permit comparison, a quantity of the original (non-electronic) data have been manually digitized in this technical report.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60721 (all parts), *Classification of environmental conditions*

IEC 60721-3-2:1997, *Classification of environmental conditions – Part 3: Classification of groups of environmental parameters and their severities – Section 2: Transportation*

[1] Lockheed Tristar KC Mk 1, Lockheed Tristar L-1011, BAe VC10 K, Boeing 747 Combi, McDonnel Douglas DC8 Cargo, Lockheed C5A (Galaxy), Lockheed C-141 (Starlifter), Boeing NC-135 (707) are the trade names of products supplied by Lockheed, BAe, McDonnel Douglas and Boeing, respectively. This information is given for the convenience of users of this technical report and does not constitute anendorsement by IEC of the products named.

3 Data source and quality

3.1 Lockheed Tristar KC Mk 1

The vibration data for the Lockheed Tristar KC Mk 1 aircraft are been taken from a Lockheed report [1] [2] on a flight test carried out in support of a US DoD program. Reference [1] reports on a single flight of a Lockheed Tristar L-1011 wide body commercial aircraft which had been undertaken to record vibration data. Measurements were recorded at two positions within the aircraft for a comprehensive range of flight conditions which are set out in Table 1.

The trial aircraft was fully fitted out. Although photographic evidence is poor quality, it indicates that the aircraft had seating and [1] indicates that it had internal fixtures and fittings and was not a bare shell. The aircraft's gross weight for the data flight was between 190 000 Kg (at take-off) and 165 000 Kg (on landing).

Measurements were made at two positions on the Lockheed aircraft as illustrated in Figure 1. The transducer positions were close to the centreline of the aircraft at fuselage stations 804 and 1 218. The centre of gravity (c of g) transducer positions are on the structure supporting the cargo bay floor whereas the forward transducers are in the roof of the cabin attached via a bracket to the aircraft structure.

The data contained in [1] seems of good quality, however, the poor quality photocopy of the original report has resulted in poor definition of some of the spectra. The electrical noise from the aircraft systems was recorded and shown to be at an acceptably low level. Bibliographic reference [1] reports that a variety of no signal data were taken to provide a measure of the noise floor of the entire instrumentation system. The noise measurement is shown in Figure 2 were made with the aircraft powered by the auxiliary power unit only.

For a number of flight conditions, (Numbers 2, 3, 7, 9 and 10 in Table 1), up to four separate recordings were taken. The set of PSDs (Figures 3 to 7) were then further reduced by presenting their average and maximum curves on one plot. This successfully demonstrated that the variation in vibration response between the separate flight recordings is small. The root mean square (r.m.s.) values computed for such cases correspond to the maximum PSD curve.

Bibliographic reference [1] states that the analysis time for each power spectral density (PSD) was at least 45 s and the analysis bandwidth was 1,272 5 Hz. These values produce a normalized random error of 13 which is generally satisfactory. Also it was reported that all the instrumentation was calibrated.

To enable the vibration responses to be overlaid on a single figure,the original data plots have been manually digitizd using up to 80 points. Where the copy of the plots was poorly defined those was simply enveloped to ensure that all the major peak responses were included in the digitizd version.

For the purposes of comparison,the data for the flight conditions were grouped into take-off and landing as well as cruise. The environment of take-off and landing includes flight conditions 2, 3, 9 and 10 (from Table 1) which are take-off, power and roll, low altitude climb, low altitude descent and touchdown. The cruise environment includes flight condition 7, high altitude cruise.

3.2 BAe VC10 K

Bibliographic reference [2] presents an assessment of vibration and shock data obtained from a flight trial carried out during April, 1985. The flight trial involved the transport of two container assemblies within a VC10 aircraft. Data gathered during the trial included

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2 References in square brackets refer to the bibliography.

measurements made at the base of the containers. The flight trial requirements and its analysis are presented in [1], [1], [5] and [6].

The trials not only included the usual benign conditions such as cruise at altitude, but also several conditions relating to emergency situations, e.g. one engine inoperative, firm landings, etc. although the scope for such emergency situations is very limited on the VC10. The full list of the various flight conditions covered during the flight is presented in Table 2.

The load configuration for the flight is shown diagrammatically in Figure 16. The payload consisted of two 1 800 Kg container assemblies. For the flight the loads were secured under normal procedures and involved lashing the load containers to the appropriate aircraft tie-down points.

Flight instrumentation consisted of 11 accelerometers, used to measure cargo hold vibration both adjacent to the airframe and at the bases of the transported containers. The airframe measurements were made on cargo floor tie-down fixtures. These being suitably firm mounting locations and available at key positions in the cargo bay. The container measurements were made at suitably rigid positions around the base of the containers, so providing a measure of vibration input. The vibration measurement sites are indicated in Figure 16.

The nature of the vibration environment is, in general, broad band random. The maximum vibration amplitudes measured at the cargo hold floor tend to occur within the 200 Hz to 600 Hz bandwidth. Consequently, the flight data have been produced in acceleration power spectral density (APSD) and acceleration-time history formats. APSD plots have been produced over the frequency range 3,25 Hz to 2000 Hz. Amplitudes from the APSDs are the result of averaging throughout a particular flight condition. Results are threfore valid for those conditions when the average properties of the data are invariant with respect to time, e.g. straight and level flight. The results of the data processing carried out are contained in [2], [1] and [1].

A statement on the accuracy of the airframe/container measuring instrumentation states that the overall tolerance is ±5,9 % with a typical value in the range ±4,0 %. The analysis resolution bandwidth was 3,25 Hz and the variance error in the range 3 % to 12 %.

To enable the vibration responses to be overlaid on a single figure the original data plots have been hand digitized using up to 80 points. Where the copy of the plots was poorly defined the poorly defined portion was simply enveloped to ensure that all the major peak responses were included in the digitized version.

No discernible shocks were observed during either normal or ‘touch-and-go' landings ([1] contains a figure demonstrating this but it is not reproducible).

Although the VC10 was originally designed and operated as a commercial passenger and freight aircraft, it is no longer operated commercially. The only known current operator is the UK military. Vibration information for this aircraft is included in this assessment because it has the potential to support the validity of data from other sources.

3.3 Boeing 747 Combi (freight and passengers)

A field study was conducted on board a Boeing 747 Combi (freight and passenger) aircraft on the route Stockholm (Arianda) via Oslo (Gardermoen) to New York (John F. Kennedy Airport) and return to Stockholm (Arianda). Shock and vibration acting on the cargo during air transportation were measured and analysed.

The study encompassed all phases of the flight, including taxiing, climbing, cruising during both calm and turbulent conditions, descent and approach, landing (including touchdown and taxiing to apron). The phases considered to be the most interesting as regards cargo-influencing vibrations and which were analysed from the field trials are as follows:

i) taxiing;

ii) take-off;

iii) initial climb;

iv) cruise, normal conditions;

v) cruise, gusts or air pockets;

vi) descent and approach;

vii) landing (touchdown, braking and roll-out);

viii) taxiing to apron.

The field data, reported in [7], were analysed by conventional frequency analysis and modelling techniques. In order to generalize the results, flight recorder data from the field trial and from other flights are included.

The fixture with the tri-axial accelerometer test set-up was mounted on the pallet with double sided tape and was placed approximately midway of the length of the pallet, about 0,5 m from the pallet edge. A fourth, separate, vertical accelerometer was mounted near the end of the pallet, approximately 0,5 m from the corner. Mounting the transducers on the pallet rather than on the aircraft deck meant that the accelerations to which the pallet was exposed, i.e. input to the cargo, were recorded. Mounting the transducers on the cargo would have meant that the accelerations recorded were dependent on the type of cargo. Of course, the products and their weight do influence the registered signals, therefore the pallet loads chosen were 'typical'. In field trial number 1 the weight of the test pallet was 1 470 kg and in field trial number 2 the weight was 2 550 kg.

The aircraft used in the field trials, a Boeing 747, is one of the most common for freight and passenger transportation. The plane in question, Dan Viking, happened to be plane number 500 in the 747 series, and was a Combi version delivered in 1981. In both trials, the pallet was placed on the main deck to the right of and close to the centre of gravity.

The field data recorded during the trip have been computer analysed in the time and frequency domains. The frequency domain analysis was carried out using both conventional spectral analysis and autoregressive modelling techniques. The sampling frequency chosen was 100 Hz and the signal was low-pass filtered at 31,5 Hz. However, since the signal/noise ratio of the recorded signal was good, the post analysis data was compensated to allow estimates up to 50 Hz to be made. This was essentially achieved by compensating for the filtering. The number of records, each spanning 256 samples, varied depending on the length of the flight phase studied. Values for the cruise phase en route have been limited to 350 records, i.e. a sampling time of about 15 min. The window mostly used for the frequency analysis was the Blackman window. For the analysis using autoregressive modelling for the spectral estimation, the Hamming window was used.

A summary of recorded extreme values and g r.m.s. values is given in Table 5. Transducer V2 is the separate, vertical accelerometer placed on the pallet corner, V1 is the vertical accelerometer placed near the pallet centre, T is the transversal accelerometer and L is the longitudinal accelerometer; V1, T and L were located on the tri-axial test set-up. Since there are no distinct dividing lines between different flight phases, the signal characteristics together with the test protocol have been used as a means of separation. In Table 5 touchdown is represented by the first four records of the landing phase.

In Table 6 the acceleration levels that can be expected to be exceeded for more than 1 % of the test time, when normal distribution is assumed, have been calculated based on standard deviations. In this case the standard deviation should be multiplied by a factor of 2,576 according to a normal distribution table. This means that 0,5 % of the values have greater positive values and 0,5 % have greater negative values. Thus, Table 6 describes the distribution of instantaneous values.

3.4 Supplementary data

3.4.1 General remark

The data collection exercise identified some additional relevant sets of information, which come from reputable sources, but for which the data quality could not be adequately verified. They are included here to facilitate validation of data from other sources. Care should be taken when utilizing information in this category.

3.4.2 McDonnell Douglas DC8 cargo

Information is contained within the French military specification GAM EG 13 ([1]) from the cargo hold of a DC8 cargo aircraft. Information is presented for three transducers and eight flight conditions. A summary of the severities for the eight flight conditions is presented in Table 7. Spectra for the most severe flight conditions are presented in Figures 24, 25 and 26. For the most part the data presented in [1] are of low level to the extent that the measurements appear close to the measurement system noise floor (see Figure 26).

3.4.3 Lockheed C5A (Galaxy), Lockheed C-141 (Starlifter) and Boeing NC-135 (707)

As part of an exercise in the early 1970’s to authenticate test severities for the US military specification Mil Std 810, J.T. Foley ([1]) at Sandia National Laboratories in the US undertook an extensive exercise to establish transportation severities on a number of platforms. One of those was for transportation in jet aircraft. Although the measurements encompassed three transport aircraft, C5A, C-141 and NC-135, the process adopted does not allow information from individual aircraft to be identified. Moreover, the analysis process Foley used throughout his work is relatively unique and not immediately compatible with other information presented in this assessment. Nevertheless, Foley did generated test spectra which can be usefully compared with those from other methods and sources (see Figures 27 to 30 and Tables 8 and 9).

4 Intra data source comparison

4.1 General remark

The purpose of the following paragraphs is to review each data source for self consistency. The process for evaluating the vibration data takes into account the variation of vibration due to operational usage and aircraft characteristics. The levels of confidence resulting from this review directly influences the levels of factoring and enveloping that are used when deriving environmental levels.

4.2 Lockheed Tristar KC Mk 1

From the data provided in [1], an assessment of the relative severity of different flight conditions, different positions in the cargo hold and different measurement axes has been undertaken to establish both the variability and characteristics of the vibration environment within the Tristar aircraft. This comparison is partly limited as the test only included a single flight of one aircraft and therefore no firm conclusions can be made regarding any aircraft to aircraft or flight to flight variations including different aircraft weights. Moreover, only two measurement positions were used giving only an indication of the variation of the vibration levels with respect to position within the aircraft.

4.2.1 Relative severity of flight conditions

The conditions of take-off, maximum power and roll provide the highest vibration levels and correspond to those that require the most power from the engines. Similarly the flight conditions for climb and acceleration produce APSDs with levels greater than cruise. Landing at touchdown specifically in the fore and aft direction also exhibits high levels but these are almost certainly as a result of the application of reverse thrust following aircraft touchdown.

4.2.2 Position within the cargo hold

In general the vibration levels for the forward transducers are higher than those recorded at the centre of gravity (c of g) for the same flight condition. This is particularly apparent for the lateral responses whose r.m.s. levels are up to four times higher. Only for touchdown are the c of g r.m.s. levels higher which is due to the application of reverse thrust and hence the higher engine induced responses in the 200 Hz to 600 Hz bandwidth. The spectral characteristics of the measurements recorded at the forward position are different to those recorded at the c of g position. Figure 8 and Figure 9 as well as Figure 12 and Figure 13 show typical vibration responses at the forward and c of g measurement positions for take-off (flight conditions 2 and 3) and landing (flight conditions 9 and 10). The responses at the forward position show consistent peak responses at 35 Hz, 100 Hz, 130 Hz and 180 Hz to 250 Hz and very low responses above 250 Hz whereas the responses at the c of g are predominantly flat with peaks in the frequency range 400 Hz to 600 Hz. Figure 10 and Figure 11 show typical vibration responses at the forward and c of g measurement positions for cruise.

4.2.3 Relative severity of measurement axes

For the responses measured at the c of g, the fore and aft direction consistently exhibits the highest vibration levels due almost certainly to the transducers proximity and alignment to the engines. The vertical and lateral responses at the c of g are broadly similar. For the responses measured by the forward group the longitudinal and transverse directions provide an equal number of the highest responses. The responses in the vertical direction tend to be lower than the other directions.

4.3 BAe VC10 K

4.3.1 General remark

For the purpose of establishing trends only data originating from the airframe sites have been considered. This is because airframe vibration, being a measure of vibration input to the cargo hold floor, constitutes the most complete description of the input environment. For the purpose of trend identification discussed below, the data have been examined in terms of overall acceleration (g) r.m.s. vibration in the frequency band 3,25 Hz to 2000 Hz and are shown in Table 3. A summary of container acceleration (g) r.m.s. vibration levels in the bandwidth 3,25 Hz to 399 Hz which excludes the power supply noise components, is presented in Table 4.

4.3.2 Relative severity of flight conditions

The vibration levels recorded during cruise were very low; the maximum being 0,156 g r.m.s. at the starboard aft (vertical) location, during cruise at 11 000 m (37 000 ft) and Mach 0,83. This is depicted in the APSD plot shown in Figure 17 where it may be seen that APSD levels do not exceed 0,000 1 g^2/Hz. The maximum vibration tended to occur during take-off, descent and reverse thrust upon landing. Vibration during these short duration events was up to four times greater than that during cruise. The maximum vibration recorded during the trials was during reverse thrust after landing. In this condition 0,674 g r.m.s. was measured at the starboard aft location in the vertical axis. The corresponding maximum APSD level was 0,001 4 g^2/Hz. as may be seen in Figure 18. No discernible differences were apparent in vibration when one of the aircraft's engines was throttled right back.

4.3.3 Position within the cargo hold

The character of vibration within the cargo hold was of increasing vibration towards the rear of the aircraft where the engines are situated. This is particularly apparent during those flight conditions which demanded high power from the engines, such as take-off. In such conditions acceleration (g) r.m.s. levels recorded at the rear of the hold were around three times greater than those towards the nose.