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THE INTERNATIONAL CONFERENCE ON NOISE CONTROL ENGINEERING
inter-noise 79
WARSZAWA - POLAND
SEPTEMBER 11-13, 1979
I1 - C

SIMULTANEOUS SHIPBOARD NOISE-AND-VIBRATION ANNOYANCE RATING

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SUMMARY

Report on a field study of the subjective equivalence of shipboard accommodation noise and vibrations. Definition of the physical "dose" by means of ISO/R 1996 noise rating scale (NR, sound pressure level in octave bands) and of a new analogous and matched vibration rating scale (VR, acceleration, mostly at discrete frequencies), evolved from VDI 2057 K-value. Definition of the subjective "effect", viz. the annoyance judgement by experienced and responsible observers (senior deck- and engineer officers, booking officers,acousticians) as expressed on simple category scales. Examples of evidence that hypothesis works: useful dose-effect correlations and no contradictory results in all 85 cases available in TPD files from 14 ships for which reliable data was obtained. Conclusion that shipboard vibration problems cannot be treated adequately without taking into account that people apparently undergo noise and vibrations on board as one coherent environment agent affecting their proficiency and their satisfaction. By means of the matched NR- and VR-scales it can be found out, whether annoyance due to noise or to vibrations prevails, and which should be considered for reduction primarily.

INTRODUCTION

Between 1960 and 1970 the need for developing criteria and limits for shipboard noise was clearly felt. At two occasions owners considering to build new passenger vessels invited us to rate the cabins and some other spaces on board their existing ships as to noise and vibration annoyance and to fix limits in close co-operation with their staffs; also at other occasions we got the opportunity to investigate this subject. On board a passenger and car ferry for North Sea service it happened during such a noise and vibration survey that highly interested and helpful stewards indicated some locations they rated as vibrating more intensely than other locations in the accommodation under investigation. Surprisingly, the noise levels apparently determined their rating of some of these vibratory-assessed places. A similar and characteristic observation can be made from a (translated) passage in a letter from an interested engineer:"... and if one is between the auxiliary engines, then the strength of the noise (and in my opinion also the vibrations of the thinner plates are part of the cause of it) is so badly annoying that one experiences a stinging headache. A kind of remedy helping me personally a little is, when I have to walk past these engines, that I do it on tiptoe, so that the vibrations are damped a bit." People on board appear to undergo the noise and vibrations as one coherent environmental agent affecting their proficiency or their satisfaction, and find it hard to assess separately the annoyance due to noise respectively due to vibrations. Partly this can be understood: noise is a particular kind of vibrations and moreover the (low-frequency) ship vibrations may cause secondary noise due to rattling etc. Partly it remains a problem, though, why people do not discern clearly between feeling vibrations and hearing noise but do so between hearing, seeing and smelling. Clearly it is a dose-effect problem and the first question is how to describe the dose and the effect.

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In this paper we limit ourselves to accommodation spaces on board, and we assume that other physical stimuli like light, odour, heat or humidity can be neglected.

HOW TO DESCRIBE DOSE AND EFFECT

There are several a priori possibilities to describe the physical stimulus consisting of simultaneous vibrations and noise. Using conventional noise and vibration measuring equipment we made our choice as reported in the following sections.

Noise and vibrations may affect several activities of people on board. We could therefore investigate proficiency scores and call this the effect. Also could we investigate the satisfaction of people, when on board or afterwards. Provided we have a measure or yard stick for satisfaction we could call this the effect. Both types of effects and their rating scores have to be assessed by the owners' responsible staff members eventually, however. We therefore assumed that the probably most useful noise-and-vibration effect descriptor is the averaged judgements by members of a noise and vibrations jury consisting of some 2 or 3 senior deck- or engineer officers, members of the crew, 1 or 2 members of the owners' staff (booking office when with respect to passenger ships; nautical or technical in general) and 1 or 2 acousticians who sail with the ship in question for several weeks, preferably, in order to know the ship, the kind of trade she serves and the members of the crew. The jury members should realize what is at stake: good working conditions, responsible seamanship and general comfort on the one side and relatively expensive technical countermeasures, the money for which can be spent differently, at the other side. They expressed their judgements on category scales running either from 0 (extremely bad) to 10 (excellent) or from C (unacceptable) to A (good) for the purposes of comfortable cross-Channel or North Sea transport of passengers or for transatlantic motorship cabins for passengers or crew. They did not know the results of the noise and vibration measurements when writing down their judgements. Each jury member spent only a few minutes in each space to be rated and a survey of some 20 cabins would take a couple of hours (the measurements not included).

A NOISE DOSE DESCRIPTOR

Sound level A seems attractive as a dose descriptor for airborne sound pressure in a cabin or other living or operational control space on board; its use in noise regulations is popular and almost universal, also for shipboard applications. In many instances there is quite a degree of correlation between the A-weighted level and other descriptors. However, we may doubt whether it meets sufficiently a basic requirement for a noise rating system, viz. that it enables its user to tell from its results which of two noises investigated is the more acceptable one. One would expect for example that a higher sound level A number always corresponds to a more annoying noise. In figure 1 dose-effect relationships are shown for 7 cases investigated on bridge wings and in wheelhouses of 4 ships [1]. Several deck officers and acousticians rated noise levels, which were due mainly to diesel engine exhausts, as to the order of acceptability under normal ship service conditions. Their average rating has been plotted as the effect (acceptable 1, less acceptable 2, the least acceptable 3). The situation numbers added to the curves indicate: location 1 and location 2 each with and without a silencer in the engine exhaust; location 3 for alternately the one or the other of two auxiliary engines; in situation 4 two locations (1 and 2) are compared before and in situation 5 after an exhaust system modification; in situation 6 three locations (1, 2 and 3) are compared also before and in situation 7 after a modification. It is clear that for 5 out of these 9 shipboard noise comparisons the noise level A fails as a dose descriptor for rating as to acceptability (less acceptable if greater A-level). In our opinion this is sufficient proof that the noise level A rating system should not be used for situations with strong low frequency components noise as are usual on board of motorships, unless with utmost care.

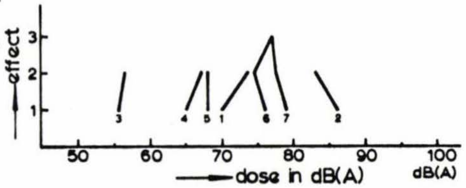

Fig.1: In 5 out of 9 comparisons for 7 situations L_A did not increase when the annoyance effect increased according to investigations in wheelhouses and bridge-wings on board 4 ships.

From figure 2 for exactly the same situations as in figure 1 it is also clear that the Noise Rating number D_{NR} shows an excellent correlation as dose-descriptor with the annoyance effect.

As this is typical for the very many shipboard noise rating cases we had to deal with, we assume that the well-known ISO/R 1996 noise rating (NR-)curves system is reliable in this respect. One can briefly describe this system as follows. The noise rating value D_{NR} is derived as the maximum value out of 9 calculated according to equation (1) from 9 contiguous octave-band noise levels L_p

$$D_{NR} = r_n(L_p - l_p) \qquad (1)$$

where the factor r_n and the level l_p run from 1,468 (NR/dB) and 55,4 (dB) for the 31,5 Hz band to 0,971 and -8 for the 8000 Hz band. The maximum value thus derived is used as the airborne noise dose descriptor. For approximately 75% of cabins in sea-going motorships D_{NR} is determined by the level in one of the octave bands 31,5 to 250 Hz (and if to 500 Hz: 90%; Buiten [6]). The cabin noise loudness levels are then determined mainly by the levels in these same bands and generally will be more than 30 dB higher than the speech interference level. In such instances there is a good correlation between the loudness level LL and the annoyance rating. This is taken into account in the definition of D_{NR} but appreciably less so in L_A (an estimate for cabin low frequency noise for $dD/dL_p \approx 1,3$ whereas for $dLL/dL_p \approx 1,3$ but for $dL_A/dL_p \approx 0,7$). Noise reduction measures should result in level reductions at the lower frequencies; this will express itself in the NR-numbers very clearly but not so much in the L_A values (as these are appreciably less sensitive to changes in the low frequency components of typical shipboard noise).

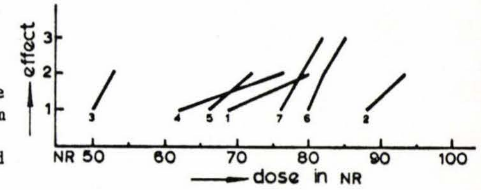

Fig. 2: For the same situations as in figure 1 the corresponding Noise Rating number shows an excellent correlation.

A VIBRATION DOSE DESCRIPTOR

In analogy to the way of describing a noise by means of a dose D_{NR} it is possible to give a definition for a vibration dose D_{VR} [2]. It is based on the old and well-known German VDI-K-values but this is not essential (we prefer the rounded-off curves instead of the edgy ISO 2631 lines; actually D_{VR} equals 40 log 10 K. If L_a represents the measured acceleration levels of the discrete frequency components referred to $1\ \mu m/s^2$ then D_{VR} is given by equation (2)

$$D_{VR} = r_v(L_a - l_a) \qquad (2)$$

where r_v equals 2 and where l_a runs from 75 dB (for 1 Hz) to 97 dB (for 125 Hz). In fact l_a is given by equation (3)

$$l_a = 75 + 10 \log \left[1 + (f/10\ Hz)^2\right]\ dB \qquad (3)$$

where f is the frequency in hertz.

Again the highest Vibration Rating value D_{VR} is taken as the vibrations dose descriptor just as in the case of the noise dose. The reasons for this definition can be summarized as follows. The range of the airborne sound pressures stimulus of interest to the subjective response (the effect) is in the order 10^4 (80 dB) whereas the vibration dose range of interest is only 10^2 (40 dB). Moreover, there are indications that a similarity exists between the subjective responses to vibrations and to low-frequency sounds (S.S. Stevens, [3]; D.B. Fleming and M.J. Griffin, [4]). The factors r in equations (1) and (2) could be approximately equal, therefore. For simplicity we retain for the vibrations dose the value 2, introduced in 1969, as it is a practical mean between 1,5 at approximately 30 Hz and 3 at approximately 5 Hz as can be derived from the equal loudness curves in this frequency range. To match the vibration rating scale to that for noise, an estimated 75 in equation (3) appeared to result in a good agreement between the NR- and the VR-scales: equal numbers in this shipboard cross-modality experiment should indicate matched acceptabilities of noise and simultaneous vibrations.

MEASURING LOCATIONS

The appropriate transducer locations should be chosen carefully, so as to characterize typically significant position doses for crew members or for passengers. Significance probably is to be determined by the positive answers to three questions:

1. Is it a noisy and vibratory object or position where the exposed subject has to

stay for prolonged periods without the possibility to withdraw to a quieter place or where important activities might be affected adversely by the noise and/or the vibrations?

2. Is the transducer location typical for the object or position?
3. Are the noise and vibration conditions typical for the normal operational conditions on board?

Typical noise (n) and vibrations (v) measuring locations consequently would seem to be:

- in the centre area of a cabin at a height of 1,7 m (n) and on the floor (v)
- near the pillow on a berth (n) and on the bulkhead to which a berth is fastened (v)
- near a desk at 1,30 m height (n) and on the table-top or on the bulkhead to which the table is fastened (v)
- at the positions of navigating officer, helmsman, pilot, etc. at 1,7 m height (n) and on the decks (v) in wheelhouse, bridge wing, crow's nest etc.
- similar in control-rooms, workshops, service spaces, galleys etc.

As it is the intention of the present noise-and-vibration rating method to present a dose description representative for the significant positions on board the ship as a structure it is not recommended to choose transducer locations e.g. on the seats of chairs, on loose tables, at fingertips or so (v) or very close to the exposed subject when present (n). For a cabin or for a space between 10 and 30 m^3 (deck area 5 m^2 approximately) the highest value either of the NR-number (n) or of the highest vectorial component VR-number as measured on decks, bulkheads or equivalent important objects is supposed to be the relevant dose-descriptor (we discontinue the logarithmic addition of these two numbers into the so-called NVR-number as published in [2]; it is superfluous and as Dr. M.J. Griffin put it in a private communication: from a scientific point of view a little unsatisfactory).

EXAMPLES

The first example is on 28 cabins on board a diesel engined passenger and car ferry NW with negligible vibrations; see figure 3. We see that more than 80% of the points fall within one category from the linear regression line (eleven-categories-scale). The second example is on 8 cabins on board a motorship of the same type KW. The vibrations were far from negligible. In figure 4 we see that on a five-categories-scale some 70% of the points fall within one category from the linear regression line (not drawn) as well for the noise rating as for the vibration rating separately. Taking the highest number of either for each cabin makes 100 % fall within this band. The third example is interesting from the point of view of vibration rating. It applies to a transatlantic cargo and passenger motorship MC, which has a certain fame as a vibratory one. All cabins were rated as "bad for a cargo motorship with passengers accommodation" (in our opinion equivalent to "strong complaints" according to the 1975 ISO Ship vibration interim guidelines for hull vibration criterion). To our surprise the vibration dose did not produce any correlation with the rating of the 11 passengers or crew cabins (many other cabins on board showed the same kind of results); see figure 5. In fact the categories A, A- and B+ did not play a role and the correlation in the noise-only rating was even slightly better than in the noise-and-vibration rating. This example has been treated elsewhere in more detail [5]. Some other examples are shown in figure 6; a point, designated by a ship code and cabin number, represents the vibrations dose plotted as abscissa and the noise dose as ordinate.

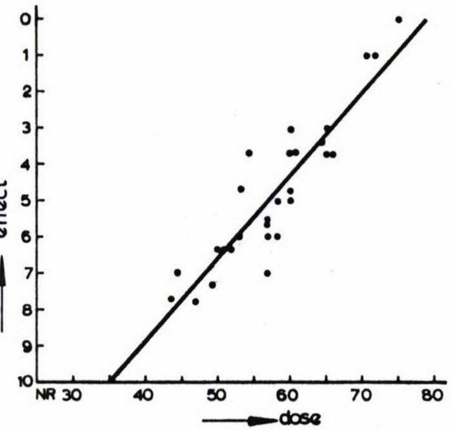

Fig. 3: Example of good correlation of NR-numbers for cabins on board passenger and car ferry NW and annoyance judgement by noise jury; vibrations were negligible. Data from TPD-files by J. Buiten; coefficient of determination $r^2(NR) \approx 0,82$.

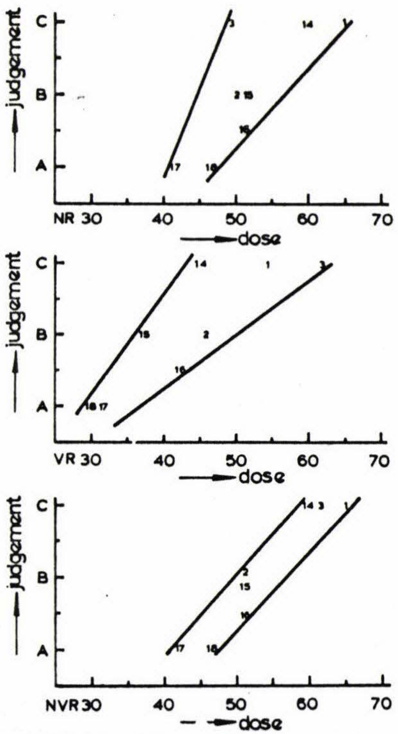

Fig. 4: Neither NR nor VR alone as dose description results in as good a correlation with the annoyance rating as does the greater of the two as dose descriptor for passenger cabins on the sea-going ferry boat KW. $r^2(NR) \approx 0,61$, $(VR) \approx 0,75$, $(NVR) \approx 0,92$.

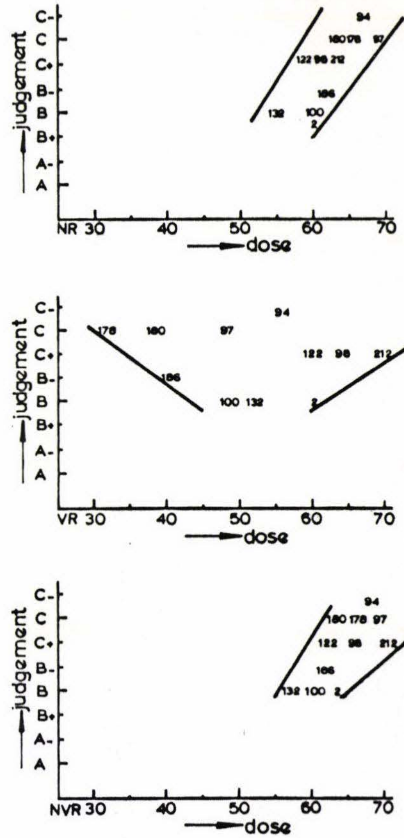

Fig. 5: The transatlantic cargo and passenger motorship MC was considered as vibratory. No good correlation could be found between VR and cabin annoyance rating, however (middle figure). Combining with noise rating turned out to be necessary. $r^2(NR) = 0,57$, $(VR) \approx 0,03$, $(NVR) \approx 0,53$.

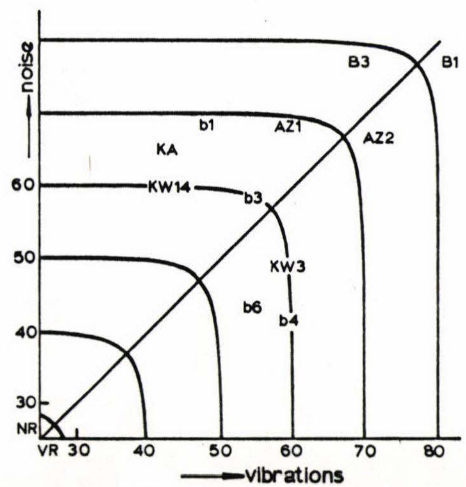

Fig. 6: Annoyance ratings of 11 cabin noise and vibration cases on board 5 ships plotted with the NR- and the VR-number as Cartesian co-ordinates. Lines of constant "logarithmically added" noise and vibration rating number facilitate orientation.

B1, B3. Harbour tug. Highly annoying noise and vibrations in two cabins; B1 clearly vibrations more annoying than noise. B3 reverse.

(See next page for caption continuation)

AZ1, AZ2. Hopper dredger. In accommodation very annoying noise and vibrations; at AZ1 noise prevailing.

b1, b3, b4, b6. Passenger and carferry. Cabin b1 out of use because of noise, cabin b3 acceptable, cabin b4 acceptable as day-cabin for chief-engineer, cabin b6 very good for passengers.

KA Cargo motorship with passenger accommodation. Strong complaints about vibrations in cabin of chief-engineer.
The point plotted represents the noise dose in the cabin and the vibrations in the centre area of the deck in the cabin. Vibrations of one of the cabin partition bulkheads correspond to VR70, however!

KW3, KW14 Passenger and car ferry. Both cabins not acceptable (C in figure 4). The noise and vibration jury on board this ship was more exacting than the one on board ship b.

CONCLUSIONS

1. There is ample evidence that people on board when assessing noise or vibration annoyance are inclined not to discern clearly between the two stimuli.
2. It has been made plausible that vibration annoyance rating of shipboard accommodation spaces should not be carried out without duly taking into account that simultaneous noise may seriously affect the judgement; also, vibrations may affect noise rating.
3. A Vibration Rating scale matched to the ISO-Noise Rating scale has been introduced.
4. It is shown that the hypothesis of using one maximum value of both the NR- and the VR-number as a dose descriptor for one specific situation is efficient and results in a good correlation with the effect, the average judgement by an experienced and responsible noise and vibration jury expressed on a category scale.
5. More research is desirable with respect to choosing/prescribing transducer locations and orientation, to refining the annoyance rating scale, to calibrating/matching the effect scales as obtained on different ships and to applying the method to various shipboard activities.

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