Proceedings of The Institute of Acoustics

# THE IMPACT AND TONAL ALLOWANCES IN BS4142 - CAN THEY BE MEASURED AND WHAT DO THEY MEAN?

DR. JAMES A. POWELL

Reader, Portsmouth Polytechnic School of Architecture, King Henry I Street, Portsmouth, Hampshire.

## 1.0 Introduction

British Standard BS4142, 1967 and ISO Recommendation R1996 are procedures which enable assessments to be made of the effect of noise on the community. They are of interest here because they have in common, the use of correction factors which are dependant upon the type of noise source, the environment in which it is heard and the psychological state of the listener. Both suggest +5dB(A) should be added to measured levels to allow for noises having impactive/impulsive character and a similar +5dB(A) allowance if there are pure tone components in the noise. For noise having both pure tone and impact characteristics it is not clear whether the allowances are additive (making 10dB(A) in all) or whether the allowance is really for an atypical signal of any sort (leading to only one allowance of 5dB(A)). The aim of this research was to investigate the nature of these allowances to determine the correct procedure.

## 2.0 Primary Objective

In particular this was achieved by determining the "loudness" effect of changing the frequency content of carrier signals modulated to simulate typical impact noises.

## 3.0 The Experiments

### 3.1 Loudness Effects

It was decided to measure "loudness" and in particular "loudness level" since as Robinson and Dadson point out, of all the semantic scales used to describe noise, loudness is the least prone to "extraneous psychological factors" which so often confound experiments. Furthermore according to Berglund and his colleagues (1976) "having done this, that is found the loudness effects, we may then seek the most suitable functional rule for modifying the loudness measurements in order that they may provide an estimate of community annoyance". They consider that such psychological rules are only measureable in a real context since they are context dependent.

### 3.2 The Signals

The impact noises used were recurrent being simulated to fall within the range of impact characteristics normally met:

i) Repetition rates 5, 10, 20, 40, 100 impacts/sec
ii) Decay times 2.2, 5.8, 9.5, 18 and 28 ms
iii) rise times less than 5 ms
iv) loudness level equivalents from 40 to 80 phons

They were generated firstly by modifying spikes, from an Aim Electronic Modular Generator, by means of a variable shaping circuit to produce exponentially decaying pulses. These pulses were used in conjunction with an analogue multiplying device to modulate white noise and pure tones (0.5, 1, 2, 3, 4, 5, 6 and 7 kHz) themselves generated by a Bruel and Kjaer Sine-Random Generator.

The results were either exponentially decaying sinusoids (figure 1) or exponentially decaying white noise (figure 2).

Fig.1.

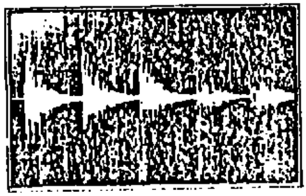


Fig.2

## 3.3 The subjects

Twenty male laboratory personnel, in the age range 18-30 were used. This number of subjects is sufficient, as Robinson and Dadson (1956) have shown, to give results representative of larger populations. Subjects were all skilled (not "trained") at loudness balancing, otologically normal, none had a hearing loss of more than 10 decibels with reference to audiometric zero.

## 4.0 Test Procedure

The subjects task was to estimate the loudness levels of various impact noises. He was seated in an anechoic room, see figure 3, a headrest being provided to locate head position. When the "warning" light on the subjects display panel went out alternative bursts of 1kHz pure tone and impact noise were presented to him. Each subject was asked to adjust the impact noise using the "double-staircase method (Cornsweet 1962), until it was "equal in loudness" to the 1kHz reference signal. Four "practice" runs were given to each subject, prior to each test sequence, to reduce any of his initial uncertainty. Subjects were given no knowledge of their results and efforts were made by the experimenter not to influence subjects in any way. In particular to avoid experimenter bias, subjects

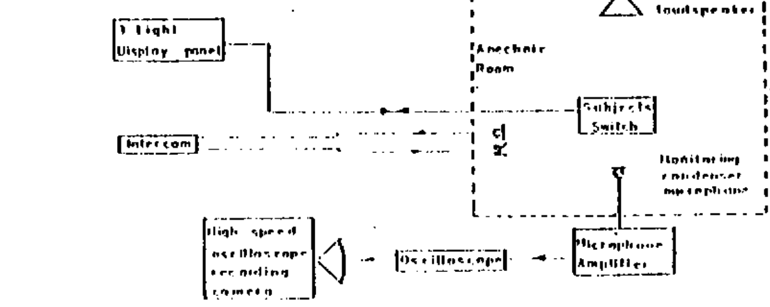



Fig. 3

A block diagram of the apparatus used in the Loudness Balance Experiments were given written task instructions prior to each test and verbal communications were kept to a minimum. For an interval of three months all subjects repeated the experiments.

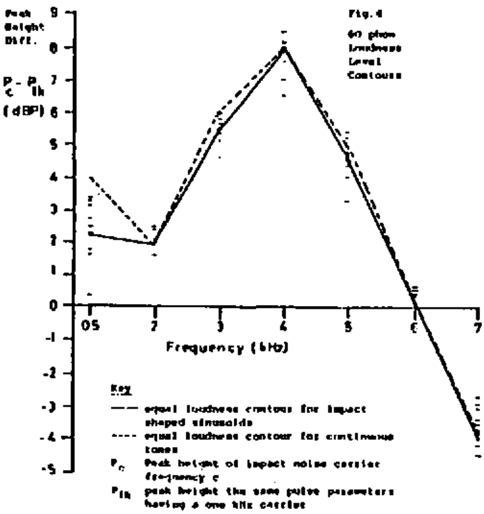
### 4.1 Measurements

The impact noises tested during the experiment were objectively measured by the standard method for assessing noise in the field together with normal physical measurements such as $L_{Aeq}$. A microphone held at a position in the anechoic room where one of the subjects ears would normally be during a test was connected directly to an integrating sound level meter in the control room; this measured $L_{Aeq}$ and other weighted sound levels.

## 5.0 Results

### 5.1 Effect of Carrier Frequency (Pure Tone Carriers)

The solid line curve in figure 4 is typical (in fact it is a 60 phon contour) and shows the effect of the frequency of recurrent impact noise carrier signal on its relative loudness. Comparisons were made between peak heights of equally loud impact noises having as the carrier 0.5, 2, 3, 4, 5, 6 and 7 kHz pure tones and impact noises of the same pulse parameter with a 1kHz carrier. The resulting curve is therefore an equal loudness contour of recurrent impact noise plotted as a function of the carrier frequency.




The other dotted curve on figure 4 shows the frequency dependance of the same subjects perception of continuous pure tones: there is excellent agreement between these two curves (with a correlation of r= 0.99, P < 0.05).

### 5.2 Loudness Enhancement caused by Impact Noise Envelope

Confirming pilot results presented earlier by Powell in 1971 the findings were that over the range of parameters studied recurrent impact noise was always perceived by the subjects as being louder than continuous noise of the same energy ($L_{Aeq}$). See figure 5 for a summary of findings in graphical form.

### 5.3 Loudness Enhancement - White Noise versus Pure Tone Carrier

The loudness enhancement provoked by a recurrent impact noise having a white noise carrier was less than the loudness enhancement produced by a recurrent impact noise similar in all respects other than having a pure tone as a carrier. This is shown quite clearly in figure 5 where the average difference between the effects of the two types of carrier amounts to 1dB.

### 5.4 Habituation and Loudness Enhancement

The loudness enhancement noted by the subjects does not appear to reduce or habituate with time. Over a two year period in which subjects were continually being tested, test and retest results were not significantly different at $p = 0.01$.

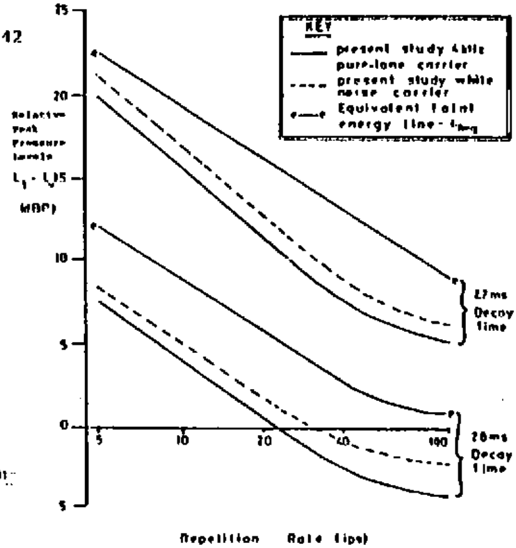



Fig.5 A summary showing relative loudness levels for extreme impact noise parameters and the equivalent energy line $L_{Aeq}$

## 6.0 Discussion

It is not possible to give a simple explanation to the above results but they are in line with similar findings by others (see Table 1) on tone bursts (due to Niese 1961) and triangular transients (due to Carter 1965). Some authors have suggested that it is the "roughness" of the impact sound that leads to its loudness enhancement; this might also account for the fact that recurrent impact noise provokes a larger loudness enhancement when its carrier signal is a pure tone rather than a white noise ; Miller (1948). The present author believes the response mechanism to be psycho-physiological in nature with the cognitive component an effect of the expectancy of the stimulus (While the recurrent impact nature of the noise will undoubtedly lead to an initial physiological response, which could provoke loudness enhancement, this response would habituate after only a short period. Since the loudness enhancement does not itself habituate with time it is suggested that the physiological effect must have been replaced by a cognitive or psychological element of the same magnitude. This view is in line with findings from other systemic studies by the present author reported to the 9th International Congress on Acoustics in Madrid.

| TABLE 1 | LOUDNESS LEVEL ENHANCEMENT OF REPEATED IMPACT OR IMPULSE NOISE OVER THE LEVELS PREDICTED BY THE FREQUENCY WEIGHTED "ENERGY LAW" LEVELS IN PHONS. | | | | |
|---|---|---|---|---|---|
| | Repetition Rate (lps) | | | | |
| Noise Type | 5 | 10 | 20 | 40 | 100 |
| Recurrent Impact Noise having a pure tone carrier (present study) | 4 | 5 | 6 | 6 | 4.5 |
| Recurrent Impact Noise having a random noise carrier (present study) | 1.5 | 4 | 4.5 | 5 | 1.5 |
| Repeated Tone Bursts (Niese 1961) | 2.4 | 2.6 | 2.0 | 1.5 | 0.5 |
| Repeated Triangular Transients (Carter 1965) | 5 | 4 | 2 | 6 | 4 |

## 7.0 Summary Conclusions

It is clear that from this research there are three basic determinants of the loudness level of a recurrent impact noise. An Energy Determinant, $\Delta L_E$, A Spectral Determinant $\Delta L_{Sp}$ and a Temporal Determinant $\Delta L_t$. They appear to be additive, so that

$$\text{Loudness Level of Recurrent Impact Noise} = \Delta L_E + \Delta L_{Sp} + \Delta L_t$$

To use this equation in practice $\Delta L_E$ and $\Delta L_{sp}$ can be equated to $L_{Aeq}$ and $\Delta L_t$ simply read off table 1 (or in short $\Delta L_t$ the enhanced loudness provoked by a recurrent impact noise having a pure tone carrier is 6dB(A) or for an impact noise having a white noise carrier the allowance is 5dB(A).

Thus for making the sort of crude allowances needed in BS4142 and ISO R1996 on the basis of loudness considerations alone, the influence for either pure tone or impact characteristics alone should be still 5dB; if they both occur together an allowance of 6dB(A) might be more appropriate.

## 8.0 Loudness Enhancements - What do they mean?

The data reported here is for the mean values of loudness enhancement caused by the impactive and sinusoidal nature of particular noises. But to what degree do loudness enhancements reflect community response and to what extent does a mean reading represent the populations response at large?

### 8.1 Mean versus Seventy Fifth Percentile Measures

If we decide to consider a larger population and satisfy 75% of the people, instead of 50%, the present research indicates that measured levels of $L_{Aeq}$ underestimate the seventy-fifth percentile by approximately 11 dB(A) for an impact shaped pure tone and 10 dB(A) for an impact shaped random noise.

### 8.2 Loudness versus Community Response

Berglund and his colleagues (1976) have reported that the functional rule linking loudness to what they call community "annoyance" for atypical noises like impact shaped pure tones and sinusoids is a multiplication factor of three. This might lead one to propose allowances in an extreme example of over 20 dB for impact noise.

On the other hand the model of loudness enhancement suggested in this research is one of "environmental expectancy". In other words it is not strictly the physical attributes of noise that provoke the level of response but rather people's expectation of its effects on themselves that govern their response. With this in mind great care must be taken in specification and use of allowances. I hope the seminar will discuss these two important caveats in detail during the afternoon discussion session.

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Proceedings of The Institute of Acoustics

# IMPACT OF TONES AND IMPULSES ON SUBJECTIVE RESPONSE

DR. JOHN W. LEVERTON
CHIEF APPLIED ACOUSTICS ENGINEER
WESTLAND HELICOPTERS LIMITED

## SUMMARY

The annoyance of Blade Slap (impulsive rotor noise) and tail rotor noise are both underestimated by conventional dB(A) measurements and require corrections in the order of 5 to 6 dB(A) when they occur in a severe form.

## INTRODUCTION

Noises containing impulses and distinctive tones have been known for a number of years to be more annoying than broadband noise with the same absolute noise level. Generalised 'corrections' to account for such effects have been recommended in a number of standard rating methods. The noise generated by a helicopter is often impulsive in character and in forward flight high levels of tonal noise can be produced as well. The impulsive noise, known as blade slap, occurs at the blade passing frequency of the main rotor which is typically in the range 12 Hz to 20 Hz and is a result of blade/tip vortex interaction or, in the case of very high speed rotors, "blade thickness effects". The 'whine' heard on many helicopters during approach is associated with the tail rotor which generally has the blade passing frequency in the 60 Hz to 120 Hz region and is akin to propellor noise. In connection with the rating of helicopter noise the subjective response of these two noise sources has been examined in depth over the last few years. The main emphasis has been placed on determining the subjective penalty compared to that associated with a "broadbandish" reference signal. This work, although specifically related to helicopters, is of general interest, since except for the specific frequency ranges considered the results are applicable to other noise sources. To date the studies have concentrated on steady state (continuous) signals, although a limited review of the influence of time varying signals (representing the flyover case) has been examined.

## CHARACTERISTICS OF SOURCES

Impulsive main rotor noise and the 'tonal whine' from the tail rotor are in essence of similar character, the only difference being the pulse frequency and the repetition rate as illustrated in Figure 1 which shows a diagrammatic representation of both sources. Subjectively, however, the sounds are very different. The 'blade slap' is akin to machine gun fire where the individual pulses can be clearly heard, while in the case of tail rotor noise the pulses merge together to produce a whine. The pulse durations shown on the figure are those typically associated with 'blade slap' and tail rotor noise and correspond to 250 Hz (repetition rate 15 Hz) and 700 Hz (repetition rate 72 Hz) respectively.

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## SUBJECTIVE STUDIES

The two forms of noise illustrated in Figure 1 have been simulated using electrical means and added to a "broadbandish reference sound" in varying magnitudes to provide signals commonly encountered in practice on helicopters. For the studies conducted within WHL a weighted white noise and a real helicopter signal have been used as the reference signals. The latter was obtained from a hovering Wessex helicopter and is free from any pronounced impulses or tones. For the main subjective studies, this Wessex recording was selected as the reference sound, since subjects found it more acceptable than the artificial white noise.

The subjective tests were conducted using a headset arrangement and in each case the 'simulated impulse and real helicopter broadband signal' was compared with the reference signal. In addition, real helicopter recordings, with alternatively high levels of blade slap (Chinook) and high levels of tail rotor noise (Scout), were compared to the reference signal. The main comparisons were made in terms of dB(A), as reported in this paper, although analysis has also been made in terms of PNL and PNLT.

In the tests the magnitude of the impulse was defined in terms of the difference btween the 'peak' of the pulse and the mean peak level of the broadbandish helicopter noise as shown in Figure 2. The magnitude of this difference was varied from 0 dB to +20 dB in the case of blade slap and -10 dB to +15 dB for the tail rotor noise. In addition to the conditions illustrated in Figure 1, additional tests were conducted in the case of blade slap for which the repetition rate was (a) varied from 10 Hz to 40 Hz with the pulse frequency fixed at 250 Hz and (b) from 10 Hz to 40 Hz with the pulse frequency chosen to ensure a constant crest factor. In these latter tests the 'peak of pulse - mean peak of broadband' was set at 17 dB. The subjective rating of 250 Hz continuous tone added to the broadband noise was also examined.

For each series of tests at least 20 subjects were used; their ages varied from 16 to 40 years and they were mainly males (80%). The majority of the subjects were given audiometric tests to ensure that their hearing was within 'normal' (20 dB) limits.

## RESULTS

The results for the blade slap (250 Hz pulse, 15 Hz repetition freq.) and the tail rotor studies (700 Hz pulse, 72 Hz repeition freq.) are illustrated in Figures 3 and 4 respectively. These figures show the correction, or penalty required, as a function of the 'peak of pulse-to-peak to broadband' In addition to the results for the simulated signals, the results obtained using the real helicopter signals are illustrated on the figures. The results for the blade slap signal where the repetition rate was varied from 10 Hz to 40 Hz with the crest factor held constant are shown in Figure 5. Also indicated on this figure is the dB(A) correction obtained from the 250 Hz continuous tone. The results for the variation in repetition rate of a constant 250 Hz pulse gave similar trends.

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## DISCUSSION OF RESULTS

As shown in Figures 3 and 4 the annoyance of blade slap and tail rotor noise in their severe form are underrated by 5 to 6 dB(A). This agrees well with the general recommendations of the Wilson Report, later incorporated into BS 4142, that a correction of +5dB(A) is required to be added to the measured level if a pronounced 'whine' or 'tone' is present.

The scatter associated with the tests in which the repetition rate was varied, was relatively large, even so the mean results show that the subjective penalty decreases with increasing repetition rate up to 25 Hz, thereafter the trends is reversed.

Tone correction procedures, as used in rating of aircraft noise, do not significantly influence the results since the values obtained are really insensitive to tail rotor noise. They also do not account for the results obtained for the 250 Hz continuous tone since the maximum tone correction usually considered is 12 dB.

## CONCLUDING REMARKS

Conventional noise rating methods do not adequately account for impulsive or tonal signals of the type encountered on helicopters.

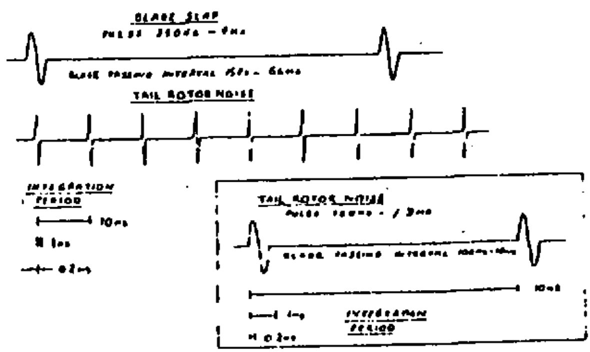

FIGURE 1 DIAGRAMMATIC REPRESENTATION

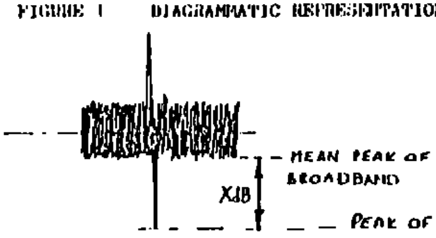


FIGURE 2: TEST CONVENTION

X dB: DIFF BETWEEN 'PEAK OF PULSE' AND PEAK OF BROADBAND

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