Paper No. 23

HELICOPTER NOISE ASSESSMENT

John W. Leverton
Head of Applied Acoustics
Westland Helicopters Limited
Yeovil Somerset

Part-time Lecturer
Institute of Sound & Vibration Research
University of Southampton

1. INTRODUCTION

ICAO/CAN Working Group B has recently turned their attention to helicopter noise and are in the initial stages of drafting rules for noise certification. This has focussed attention on the problems of rating helicopter noise which, until recently, has simply followed concepts adopted for traffic noise or aircraft noise. It has been well known in the helicopter industry that these methods were inadequate and although this has been clearly shown by a number of investigators, it has only recently been given serious consideration. The noise radiated by a helicopter is very complex since it is a combination of the sound produced by several individual sources, which in the main generate acoustic energy by more than one mechanism. Externally the noise is controlled largely by the noise from the rotors, although the high frequency compressor 'whine' is subjectively significant at distances relatively close to the helicopter. From the subjective point of view, the two most important sources are 'blade slap' and 'tail rotor' noise. Blade slap is a loud 'banging' noise which occurs at the blade passing frequency. It is mainly associated with tandem rotor helicopters and those helicopters with a two bladed single rotor, although it can be generated to some extent on practically all helicopters. Tail rotor noise is radiated in flight as a distinctive whine ahead of the helicopter and, on the smaller type of helicopter, it is often the most pronounced noise during cruise.

2. BACKGROUND

Following a review of the problems involved in rating helicopter noise (ref. 1), it was fairly clear that the conventional PNL and dBA methods being employed do not adequately account for the subjective effects when the sound is dominated by high levels of impulsive main rotor (blade slap) noise and/or tail rotor noise. To date, however, there has been no real attempt to determine the subjective penalty or weighting associated with these two sources. It would appear that in the case of the former this is partly due to the difficulties of quantifying the impulsive characteristics. In an effort to overcome this problem an experimental study has been carried out, using a wide range of helicopter recordings, to determine the most suitable method for differentiating between non-banging and banging helicopters. There has been no attempt to determine the corresponding subjective weighting since this obviously requires a full subjective survey, although a tentative method for rating blade slap has been developed. This work has been backed up by a simple theoretical study of the influence of varying the integration or averaging time on the analysis of impulsive signals. This is reported in this paper, together with a brief review of difficulties of rating tail rotor noise.

3. BLADE SLAP - IMPULSIVE MAIN ROTOR NOISE

3.1. SCOPE OF INVESTIGATION

Ollerhead (ref. 2) using spectra which varied from pure jet aircraft to rotorcraft, found that there was little difference among the various rating units including PNL and dBA. It is also well known that there is, for all practical purposes, a constant dB difference between PNL and dBA values. For these reasons, and since dBA values can be easily obtained, the main emphasis of the recent investigation has been placed on dBA analysis. Because of the high levels of low frequency noise on a helicopter, dBLIN (unweighted) levels are often quoted and thus dBLIN analysis was also performed. Some PNL calculations are planned and for this a limited amount of $\frac{1}{3}$ octave band analysis has been carried out. There may be some problems with the PNL approach, however, since with the impulsive signals the standard $\frac{1}{3}$ octave band filters tend to 'ring' and hence give false results. The overall influence of this on the final PNL values has, however, not been established to date.

From the results of the earlier studies (ref. 1) and the initial phase of this investigation it soon became clear that it was necessary to consider the 'peak' amplitude of the signal and, as a consequence, the determination of the 'crest factor' seemed a practical method of defining the impulsive nature of helicopter noise. The 'peak' amplitudes were derived from calibrated UV and oscillograph traces. This is, however, a relatively involved process and although in the case of helicopters with high levels of blade slap, the bang (peak) levels could be easily read it is much more difficult to determine the level in the case of non-banging helicopters which give a trace with a broadband random noise appearance. This general approach, however, gave encouraging results and was further refined by following the results of a study presented in reference 3, which indicated that the bang energy could be isolated in a relatively narrow-band between 100-400Hz. This frequency band was confirmed and crest factors appropriate to this range derived. The crest factor approach appeared from the results obtained to offer a positive method of quantifying helicopter noise and, to overcome the difficulties of obtaing such data, a standard B & K Impulsive Sound Level Meter (type 2209) was modified to give a direct (DC voltage) read out of the 'peak' level. This was subsequently changed to enable the envelope of the 'peaks' to be plotted directly.

3.2. SUBJECTIVE SCALE

Before any subjective rating could be applied to impulsive helicopter noise, it was essential that an analysis method had to be established which differentiates between a non banging and banging helicopter. With this as the main aim, the programme discussed below was carried out. Before this could be commenced it was necessary, however, to provide a 'scale' for evaluating the suitability of the various analysis units/methods and for this the helicopters were simply 'ranked' in order of blade slap severity by the small analysis team at Westland Helicopters Limited. Initially the helicopter recordings were grouped into bands according to their severity of blade slap in a similar manner, and using the same designations, as those recently used by Munch and King (ref. 4) in a study of the community acceptance of helicopter noise (see figure 1). The helicopters within these bands were then further ranked to give an indication of their subjective differences. Since, however, this process was only carried out by a small team under normal laboratory conditions, the scale should only be taken as an indication of their relative subjective effects.

This reference scale was chosen prior to the commencement of the tests and then fixed - thus different methods of analysis used the same scale and the aim of the study was to find a unit or analysis method which would give a similar variation. In the case of one helicopter, the Bell UH-1B, some difficulty was experienced in determining the appropriate rating since, in addition to blade slap, it generated a high level of conventional main rotor rotational noise. There was a tendency to give a higher rating for the non blade slap condition, than warranted if only blade slap was being considered and the final subjective rating was only selected after repeated listening to recordings of this helicopter with and without blade slap.

3.3. 'RMS' ANALYSIS

dBA RMS 'SLOW' and dBLIN 'RMS SLOW' were used as reference levels for the analysis. Helicopters generate relatively high levels of low frequency main rotor noise; this can vary significantly from helicopter to helicopter and have a major effect on the measured dBLIN value. dBA measurements are influenced less by the degree of low frequency main rotor noise and since the main aim was to see if the impulsive noise could be quantified, emphasis was placed on the study of dBA weighted measurements. For comparison, however, the corresponding dBLIN levels were also determined. For the analysis reported in this paper, either meter results or level recorder DC output results have been used.

3.4. IMPULSIVE NOISE - RESULTS

A selection of the results, which illustrates the general findings, are plotted against the subjective scale discussed previously in figures 1 to 6. For convenience the following abbreviations are used Lin ~ dBLIN; 'A' ~ dBA, IMP ~ IMPULSE and SLOW ~ RMS 'SLOW'.

For the results obtained using meters and/or level recorder traces, and hence derived from RMS circuits, the mean values have been quoted since the variation in the mean is relatively small. In the case of the crest factors which have been derived from 'peak' levels read from UV and/or oscilloscope traces the results exhibit a fair degree of scatter and for this reason, the range of results have been indicated on the figures. The hover data is quasi steady state and the data quoted refers to the mean over the full length of the recordings which are typically of 30 seconds duration. For the flyover analysis the results refer to the instants at which maximum blade slap occurs which, except in the case of the Bell UH-1B at 120 knots, occurs for all practical purposes at the same time as the maximum dBA level. For the Bell UH-1B the results refer to a period just prior to the flyover 'peak' when, as determined subjectively and from UV analysis, the blade slap is most noticeable.

As can be seen from figures 1 to 3, there is no real correlation between the 'IMPULSE - RMS SLOW' results and the blade slap rating. Although the actual numbers in dB obtained are dependent on the weighting used - i.e. dBLIN or dBA - there is little difference between the general trends associated with these two types of analysis. Use of Crest Factors improves the correlation, but as illustrated in figure 4, this is still relatively poor if unweighted dBLIN (LIN) values are used. This is largely due to the influence of low frequency main rotor noise and, hence, 'A weighting' the signal improved the position. This can be seen in figure 5 which shows a relatively good correlation between the subjective rating and the measured dBA Crest Factors.

The blade slap impulse contains significant energy around 250Hz and it can be shown that, for a wide range of helicopters, the magnitude of the bang can be measured by filtering out the signal below 100Hz and above 400Hz. This approach was used in this study to give the bang crest factors and the results are shown in figure 6. As can be seen, good agreement is shown with the subjective rating and relative to the dBA analysis (figure 5) the scatter or variation about the mean is reduced.

3.5. DEVELOPMENT OF ENVELOPE DETECTOR

It seemed clear that the 'crest factor' approach offered a convenient method of quantifying helicopter noise, but there are difficulties in reading the U.V. traces and it is a relatively involved process to obtain the peak levels. In an attempt to overcome this problem and enable, in due course, automatic plots of the crest factors to be obtained, a Bruel and Kjaer Impulsive Precision Sound

Level Meter (type 2209) was modified to enable 'peak' levels to be obtained automatically. Initially this involved simply overriding the 'peak' hold circuit (which has a 10μsec. rise time) and incorporating a 50m. sec. decay time constant. This gave a very 'ragged' output and to overcome this a diode detector, similar to that used in AM radio receivers, was added to form in effect, a 'peak' envelope detector. Although this was only considered as an interim solution, it has been used to obtain 'peak' levels and subsequent crest factors. Further developments planned include changing the rise time which is considered too rapid for normal helicopter noise to 5m.sec. and linking it with a second B&K 2209 meter to enable a direct plot of the difference between the 'peak' and RMS SLOW value to be obtained.

3.6. ENVELOPE DETECTOR - INITIAL RESULTS

Two sets of data derived from 'peak' levels measured using the Envelope Detector are shown in figures 7 and 8. These correspond to the crest factor results presented in figures 5 and 6 and although the actual values show variations in the order of $\pm$ 1dB, the general trends are similar for the helicopters with the higher levels of blade slap. For the non-impulsive helicopters the 'peak levels' obtained are higher than the corresponding values obtained with UV and oscilloscope forms of analysis. This is due to the high rise time of the detector (10μ sec.) which responds to even extremely rapid transients. These pulses are effectively 'damped' out by the UV analysis and are so fast that they can not be seen on the oscilloscope. Since they also appear subjectively unimportant, the rise time constant is, as mentioned previously, being modified and then values similar to those shown on figures 5 and 6 should be obtained.

3.7. THEORETICAL STUDY

Although helicopter noise is complex in character, it is clear from simple theoretical considerations that a very short integration period is required if the influence of the 'peak' level is to be assessed. Figure 9 shows the dB differences resulting from the use of various integration times on an impulse of the form associated with blade slap. The upper and lower curves give the generalised maximum and minimum values for an ideal (digital) detector. Also indicated are the values corresponding to SLOW, FAST and IMPULSE meter circuits. This figure also shows that the difference between IMPULSE and RMS SLOW will always be small (approx. 2.5dB) and that a very short integration time, in order of 4m.sec., would be required to give a true measure of the 'peak' level of the signal.

3.8. DISCUSSION OF RESULTS

The results obtained show that the crest factor could be used to quantify helicopter noise. Results based on filtered data which rejects the signal below 100Hz and above 400Hz would appear to offer the best correlation, although crest factors based simply on dBA levels could be used.

It follows that a simple add on type correction for impulsive helicopter noise is possible. If such an approach is adopted then it would appear from the limited data presented that, if the crest factor is 12dB or less, the correction should be zero. This is in good agreement with the investigations reported in reference 4, which indicated that the boundary for the existance of blade slap was a crest factor of 13dB. Obviously the next stage would be to determine accurately the subjective dB correction. In some very early work conducted at the ISVR in 1968 it was concluded that, relative to the dBA RMS SLOW value, a banging V107 helicopter was 6dBA more annoying than when in a non-banging condition. Taking this into account together with the appropriate crest factors of the data used in the ISVR study, and the general statement that a helicopter which generates marked blade slap is 10dB or more annoying than a non-banging helicopter, then it would appear that the correction or penalty would take the form presented in figure 10. This shows values relating to both dBA and the filtered (100-400Hz) analysis and at this stage must only be taken as a tentative indication of the correction for blade slap. For comparison the Impulse Noise Annoyance Penalty recently proposed by Munch and King of Sikorsky Aircraft (4) is shown and as can be seen there is general agreement except at the lower crest factors.

Is such an approach was considered acceptable then the dB correction would be simply added to the appropriate PNL or dBA time history to give an impulse corrected value (i.e. IPNL or IdBA).

4. TAIL ROTOR NOISE

Tail rotor noise is, as already mentioned, an important source of helicopter noise particularly in cruise flight, It shows up on narrowband analysis as a series of discrete frequencies at the fundamental blade passing frequency and its harmonics. Clearly there is a need for a correction to account for this aspect but, in the opinion of the author, the tone correction procedure in the PNL aircraft type noise analysis is inadequate. There are a number of studies which have indicated that such corrections only enhance the annoyance prediction for tones above 500Hz. The fundamental frequency of tail rotor noise is typically in the range 85Hz to 125Hz and thus clearly tones below 500Hz should be taken into account. Even so it appears from the studies conducted by the author that even when tail rotor noise subjectively dominates the helicopter noise, the tone correction applied is only 1/2dB. Unfortunately, there is little or no subjective evidence available and thus it is difficult to quantify the problem. Further analytical studies have been conducted at Westland Helicopters Limited and these substantiate the findings presented in an earlier paper (Ref. 1). It appears that even when the helicopter noise is subjectively dominated by tail rotor whine, it is only the $\frac{1}{3}$ octave bands which correspond to the fundamental and, in some cases, the second harmonic which are increased. This gives, even in the case where tail rotor noise is most pronounced, only a 3PNdB increase above the corresponding no tail rotor noise condition. This is relatively small when compared to the subjective impression. Recently PNL and TPNL values, as a function of time, have been compared for helicopters with high levels of tail rotor noise and those with very low levels. These results tend to confirm earlier results and show that the tone correction is for all practical purposes always the same level irrespective of the type of helicopter.

5. CONCLUDING REMARKS

RMS SLOW and IMPULSE settings are insensitive to blade slap and thus can not be used for rating impulsive helicopter noise. It has been shown, however, that helicopter noise can easily be quantified in terms of crest factors providing that A weighted or band limited (100-400Hz) signals are used. This offers a practical method of rating helicopter noise but before the magnitude of the corresponding dB corrections can be determined, a detailed subjective study is required. In the meantime it would appear that corrections of the form indicated in figure 10 should be applied.

The situation relating to tail rotor noise and the applicability of conventional tone correction methods is far from clear and requires further consideration. As in the case of blade slap it would appear that the first step would be to derive a simple method for its quantification during a flyover. Although at present it is difficult to imagine how a suitable correction could be applied, there is enough evidence to indicate that it should be taken into consideration when assessing the noise of a helicopter.

ACKNOWLEDGEMENTS

The author wishes to thank colleagues in the Westland Applied Acoustics Department for their help in preparation of this paper; in particular Barrie Southwood who was responsible for the impulsive noise analysis programme and Antony Pike and Rodney Mattravers who developed the envelope detector. Views expressed in this paper are those of the author.

REFERENCES

1. John W. Leverton, "Helicopter Noise: Can it be Adequately Rated?" Proceedings of Symposium on Noise in Transportation, University of Southampton (July 1974).

2. J.B. Ollerhead, "An Evaluation of Methods for Scaling Aircraft Noise Perception". NASA CR-1883 (October 1971).

3. John W. Leverton, "Helicopter Noise - Blade Slap; Part 2: Experimental Results" NASA CR-1983 (March 1972).

4. C.L. Munch and R.J. King, "Community Acceptance of Helicopters, Noise: Criteria and Application" NASA CR-132430 (June 1974).

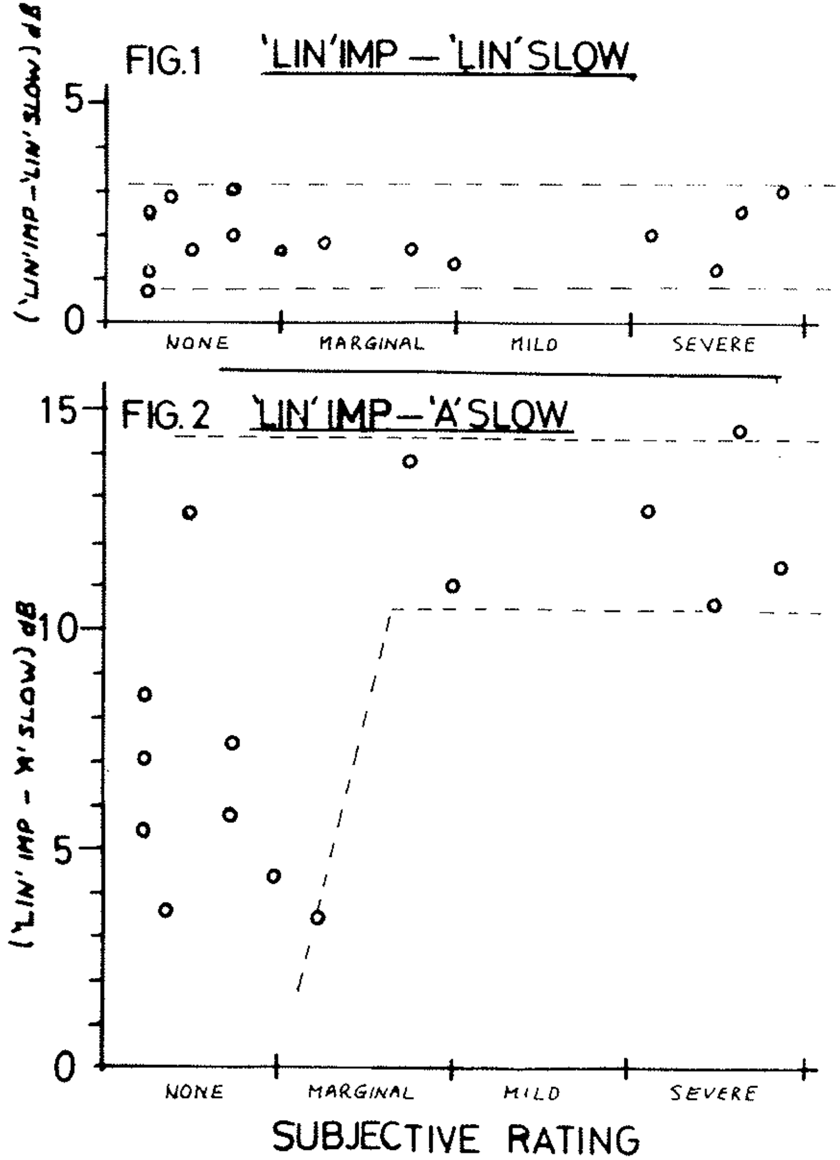


FIG.1 'LIN'IMP — 'LIN'SLOW
('LIN'IMP – 'LIN'SLOW) dB
5
0
NONE
MARGINAL
MILD
SEVERE
FIG. 2 'LIN' IMP — 'A' SLOW
('LIN' IMP – 'A' SLOW) dB
15
10
5
0
NONE
MARGINAL
MILD
SEVERE
SUBJECTIVE RATING

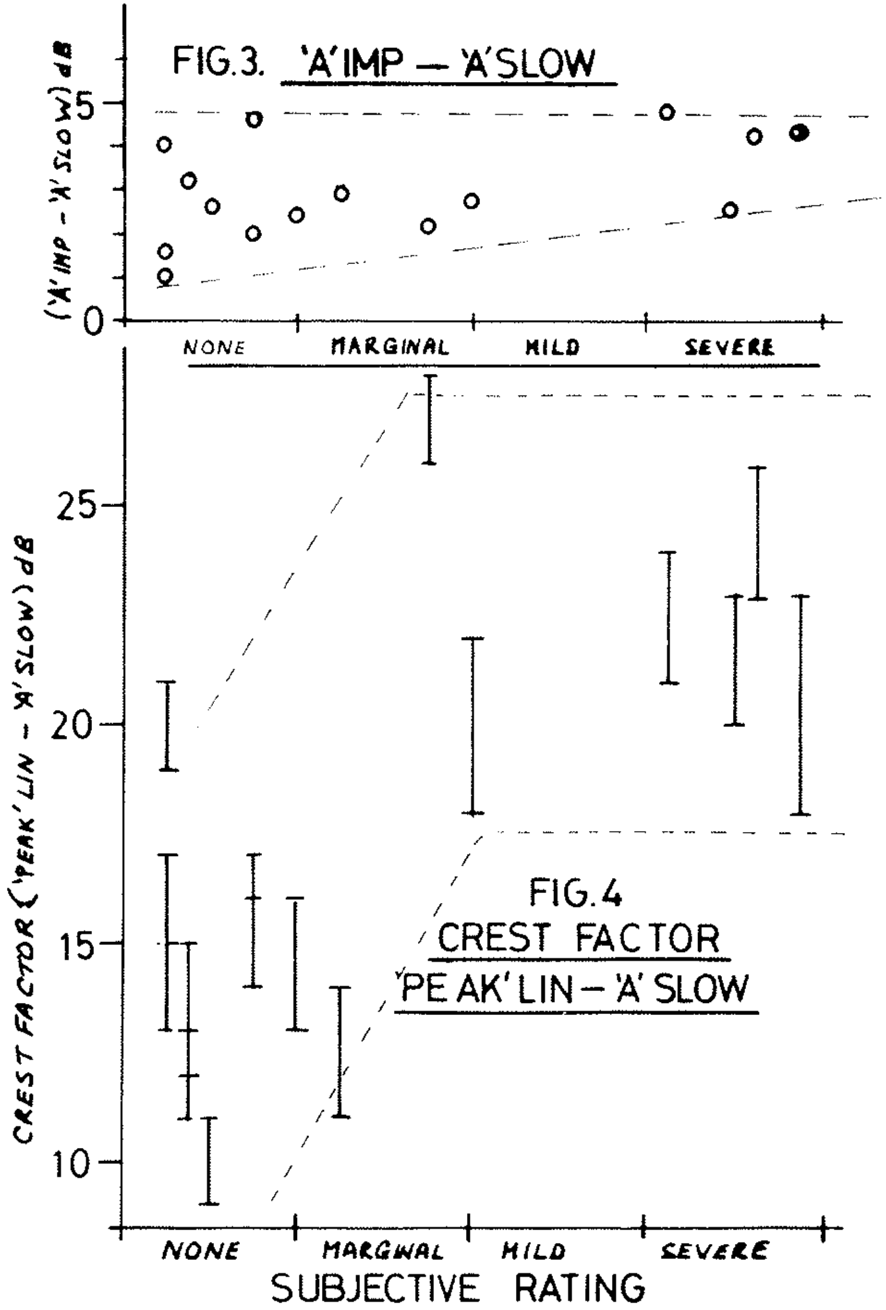


FIG.3. 'A' IMP — 'A' SLOW
('A' IMP – 'A' SLOW) dB
5
0
NONE
MARGINAL
MILD
SEVERE
FIG.4
CREST FACTOR
'PEAK' LIN — 'A' SLOW
CREST FACTOR ('PEAK' LIN – 'A' SLOW) dB
25
20
15
10
NONE
MARGINAL
MILD
SEVERE
SUBJECTIVE RATING

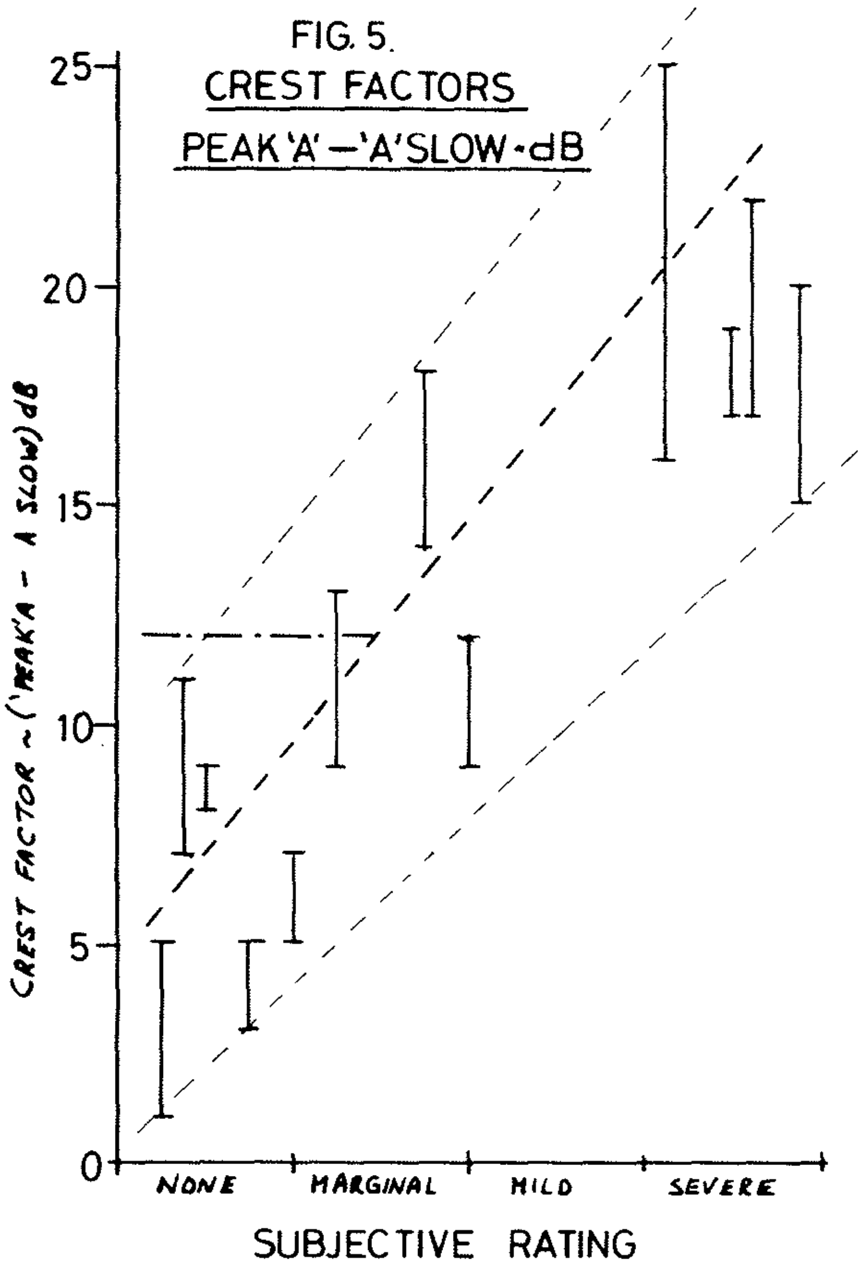


FIG. 5.
CREST FACTORS
PEAK 'A' — 'A' SLOW - dB

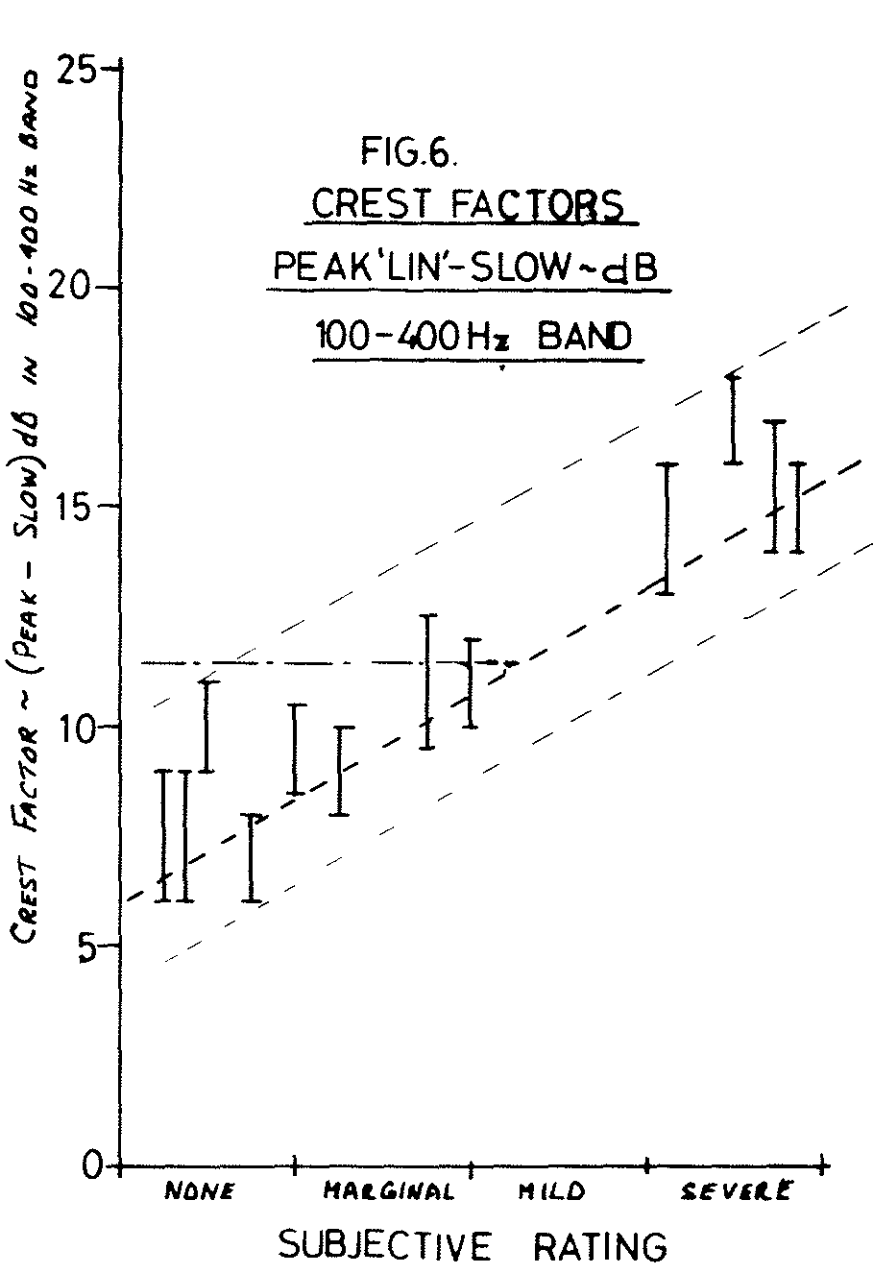


FIG. 6.
CREST FACTORS
PEAK 'LIN' - SLOW ~ dB
100-400 Hz BAND

FIG. 7

CREST FACTORS USING ENVELOPE DETECTOR PEAK 'A' – 'A' SLOW ~ dB

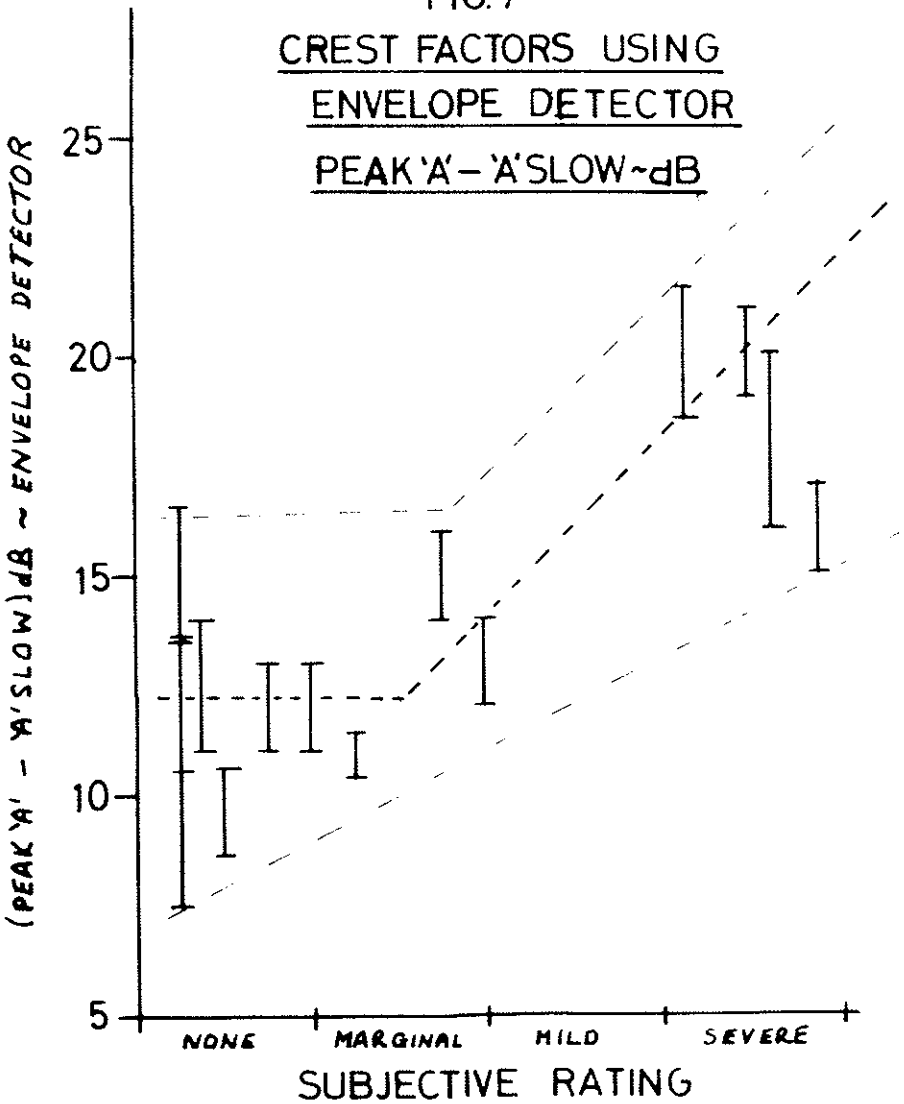
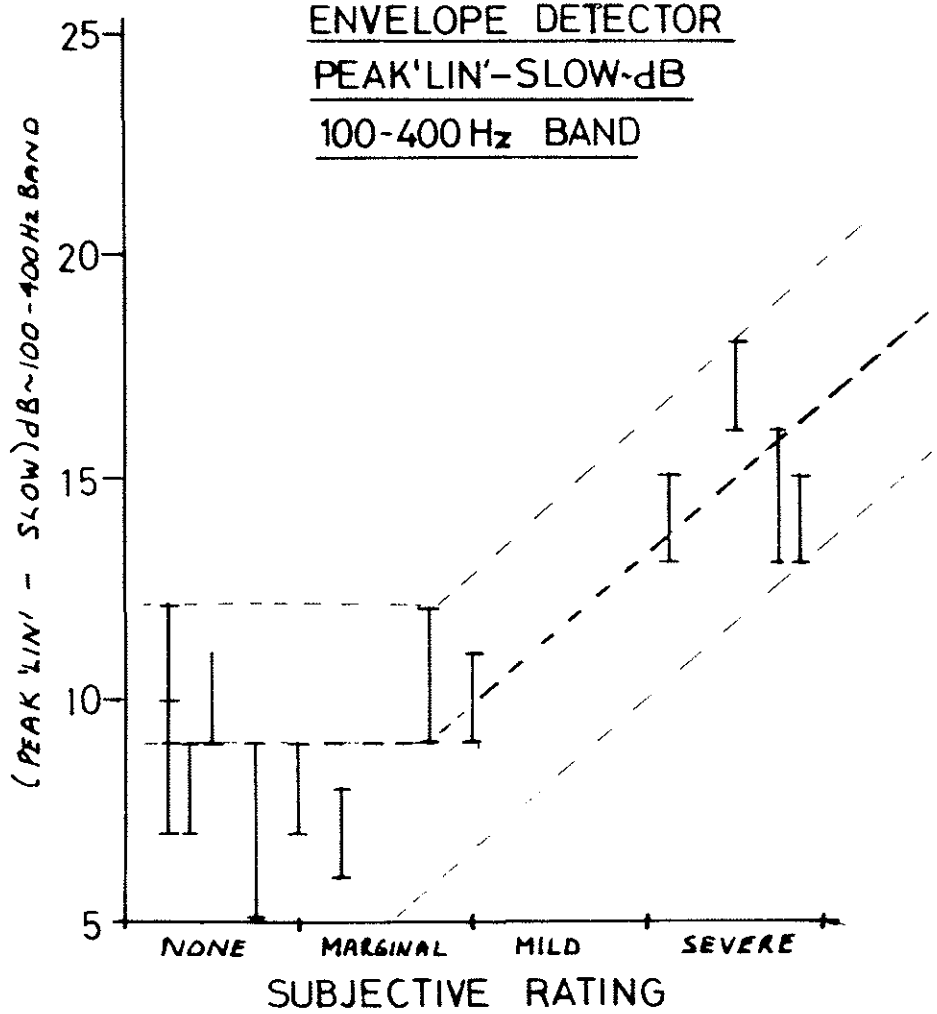


FIG. 8.

CREST FACTORS USING ENVELOPE DETECTOR PEAK 'LIN' – SLOW ~ dB 100-400 Hz BAND



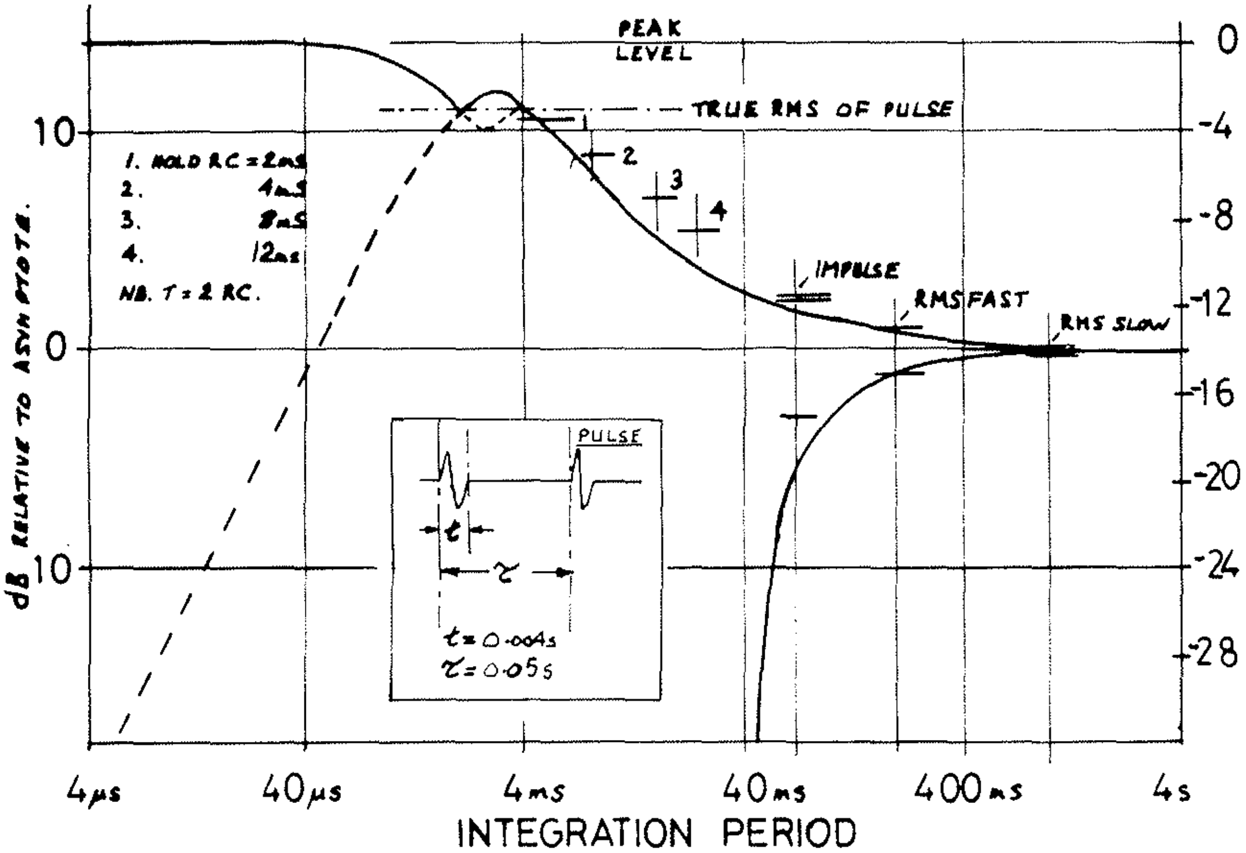


FIG.9. EFFECT OF INTEGRATION TIME ON 'MEASURED' LEVEL.

FIG.10
BLADE SLAP - IMPULSE CORRECTION TENTATIVE PROPOSAL