

## RATING HELICOPTER NOISE

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## SUMMARY

In the case of helicopters the main problem from the community point of view is the noise heard on the approach. This is particularly true in the case of helicopters with high levels of blade slap and/or tail rotor noise. The EPNL concept does not appear particularly well suited to quantifying helicopter noise since it is insensitive to the noise heard on approach some distance from the flyover position. Blade slap and tail rotor noise both need an additional correction. The former is now readily agreed and preliminary evidence is presented to show that a similar correction is required in the case of tail rotor noise. The impact of the use of such corrections is examined and although they improve the correlation, with the practical situation there is still considerable difficulty due to the inherent characteristics of the EPNL procedure.

## INTRODUCTION

The use of helicopters for general commercial purposes has continued to increase and although in many instances they operate from remote sites on specialist operations, their use within built up areas has continued to grow. As a natural consequence overflights over many areas far from heliport sites have showed a significant increase. In urban areas, well-defined flight paths have been established for safety and ATC reasons and, as a result, there has been a tendency to concentrate flights over particular locations. This wider use of helicopters has given rise to concern over noise and although the number of complaints are still small, they have tended to increase over the last few years. The noise levels of helicopters have also shown a tendency to increase as modern technology has allowed high speed rotors to be employed and helicopters with higher forward flight speeds. Noise certification for helicopters has now been under consideration by the ICAO Working Group B for a number of years and certification proposals are expected shortly. There appears to be a need, therefore, to re-examine the whole topic of external helicopter noise and the results of such a survey conducted by Westland Helicopters Ltd. (WHL) are presented in this paper. In this context it is worth noting that in addition to manufacturing helicopters, WHL operates the London (Battersea) Heliport and has been involved in helicopter/community interface problems encountered by the British Army of the Rhine in West Germany. The WHL airfield is also situated within the boundaries of a small town; thus, considerable experience has been gained from the operators, manufacturers, and community point of view. The author has also been closely involved, as an adviser to the United Kingdom (UK) delegation, with the ICAO Working Group B.

## HELICOPTER NOISE - THE REAL PROBLEM

In the case of helicopters the main noise problem from the community point of view is the noise heard on approach. This is particularly true in the case of helicopters with high levels of blade slap and/or tail rotor noise. It is the noise heard at distance which is of main concern. If this noise is impulsive (blade slap) or contains a distinctive whine (tail rotor noise), then it readily attracts attention, becomes disturbing, and, because it can be heard for a relatively long period as the helicopter approaches, gives rise to complaints. In many cases, but not always, blade slap decreases rapidly in level as the overflight position is approached. Similarly, on practically all helicopters with a high degree of tail rotor noise, the noise dies away well before the overflight point is reached. This is due to the directional characteristics of these two noise sources.

The effects discussed above are illustrated in figures 1, 2, and 3 which show time histories (amplitude - time traces). Figure 1 shows results for a two-bladed single rotor helicopter with and without blade slap where the blade slap decreases just prior to the overhead position; as can be seen, there is a marked difference in the duration of the noise. Also indicated on this figure is the blade slap region and the "peak levels" determined using a peak detector developed within WHL. This, in effect, gives a measure of the blade slap and a true representation of the duration associated with this helicopter. The data on this figure, like that on figures 2 and 3, are unfortunately limited in the sense that the recordings were not taken over a sufficient time period, (the data were collected as a part of other studies) and, as a result, the true duration above the background noise cannot be shown. The general implications are, however, clear. Figure 2 shows results again for a helicopter with blade slap but in this case the blade slap occurs during the complete flight. These data were obtained from a tandem rotor helicopter and are typical of the noise levels generated by this type of helicopter. Indicated on the figure is the 'peak' level for the blade slap case and the dB(A) level for the same helicopter when flown (during special tests) with no blade slap. Figure 3 shows the corresponding results for a helicopter with a high degree of tail rotor noise compared with a helicopter which has a low level of tail rotor noise. As can be seen, the duration is increased when tail rotor noise is present.

From a review of test data and a brief review of complaints and observation of helicopter noise, it has been concluded that although in many cases the absolute level of helicopter noise is highest at the overflight position, the annoying characteristics have decreased and there is little notice taken of the maximum overflight noise. This is not to imply that the complaints against helicopter noise are completely independent of the level since obviously a low altitude flyover which generates a very high level will prompt an adverse reaction. In the real environment helicopters are typically 500 ft (150 m) or more from the nearest residence and then it would appear that the character of the noise is equally, or more, important than the absolute level. There has, however, been little or no technical studies into these aspects, although experience gained from helicopter flights over London and generally within the UK supports these general observations.

According to Greater London Council there is in London "a small but steady flow of complaints about noise" (ref. 1). Yet, when 230 occupiers of properties within the vicinity of the London Battersea Heliport were contacted, only 3 objections on noise were received. In fact, there appears to be more objections from locations well away from the heliport; this result agrees with the conclusion from the WHL review that the main problems arise from the noise generated on approach. In this context it is also worth noting that in addition to the absolute level of helicopter noise decaying rapidly after the overflight point is reached, neither blade slap nor tail rotor noise is thereafter subjectively detectable.

In the practical situation, high noise levels are generated during "bank turns", manoeuvres etc. prior to landing and take-off at heliports. These are obviously a function of the specific flight procedures used or the ATC constraints and thus should not be included in any certification scheme. They can, and do, however, have a major influence on the subjective reaction to helicopter noise and it would appear from the available evidence that it is such aspects which define the acceptability to the general public of a particular helicopter near a heliport. The details of the flight path are important in this context and if they are chosen such that a helicopter has to turn sharply to avoid overflying a particular location, this can often generate higher noise levels than would occur if the helicopter was allowed to fly overhead.

#### RATING HELICOPTER NOISE

It follows from the points outlined previously that since the annoyance of a helicopter is largely dependent on the noise heard on approach that any rating or certification scheme for helicopters should be completely different from that derived for fixed wing (CTOL) aircraft. This should take into account the subjective character of the helicopter noise on approach some distance from the flyover point and the time associated with the noise, as well as the maximum level measured during the overflight. It is often argued that it is not the role of certification to control the "operational noise situation", but blade slap noise and tail rotor noise are of fundamental importance in the case of the helicopter, particularly since these noise sources can occur during "straight and level" cruise flight. This is a very different situation from that associated with fixed wing aircraft and therefore, by implication, the traditional method of rating aircraft noise is basically inappropriate. It is difficult, however, to imagine how a "new scheme" for helicopters could be formulated particularly since the various certification authorities place significant emphasis on developing a scheme which is, as far as possible, compatible with 'fixed wing' procedures. As a consequence, the helicopter noise certification concept currently being considered with the International Civil Aviation Organization (ICAO) and by the Federal Aviation Administration (FAA) are based on the EPNL method which is dependent mainly on the absolute level of the noise and the duration between the '10 dB down' points.

The EPNL method also takes into consideration the tonal content of the noise and thus it would be expected that it would take account of the subjective

impact of tail rotor noise as well as the high frequency engine 'whine.' Preliminary studies within WHL suggested that this is not the case and that the 'tone corrections' are often, to a first order, independent of the level of tail rotor noise. This is a complex subject and there has been very little work on this topic to date, but it would appear from analysis made by the author that problems arise from the fact that helicopter noise, particularly below 500 Hz, contains many discrete frequencies from the main and tail rotor and the one-third octave band spectra is not a true reflection of the annoying characteristics of the tail rotor noise. To remove the uncertainties of applying the tone correction procedure, ICAO Working Group B suggested at one stage that tone corrections should be applied only above 500 Hz, but recently this approach has been dropped and the latest view appears to be that tone corrections should be applied over the complete frequency range as in the standard EPNL procedure (Annex 16).

As mentioned previously, blade slap is the most annoying source associated with the helicopter. There is ample evidence to show the inadequacies of the standard EPNL procedure and that an additional correction factor is required to account for this source. There is, however, some opposition to this procedure and, although the International Organization for Standardization (ISO) has proposed a procedure for accounting for blade slap, this has not received wide acceptance in the U.S.A. In fact, it would appear that even some groups, which have accepted in principle that a blade slap correction is necessary, are more concerned with developing alternative schemes rather than assessing the relative merits of those already proposed.

The concern over the suitability of the use of the EPNL concept for rating helicopter noise will still apply even if a blade slap correction is finally accepted. The adoption of such a correction will, however, significantly improve the rating of helicopter noise relative to the use of an unmodified EPNL.

#### RATING UNITS

It is not proposed in this paper to review the various units for rating helicopter noise since it is clear that for a number of reasons the perceived noise level (PNL) will be used as the basic unit with possibly the dB(A) in some situations. Intuitively, it would be expected that the PNL method should adequately account for helicopter noise providing the signal is relatively broadband in nature and without any pronounced discrete noise sources. Also, since it is used for rating CTOL aircraft, it should also be equally applicable for rating helicopter engine noise. It follows, therefore, that with the exception of the cases when the signal is dominated by blade slap and/or tail rotor noise, the PNL unit, and by implication the dB(A), should be suitable for rating helicopter noise. For blade slap and tail rotor noise, some additional correction terms are required and this is discussed in the following sections.

## BLADE SLAP

### Correcting for Blade Slap

It is clear from the studies conducted within the UK by the National Physical Laboratory (NPL) and WHL (refs. 2 and 3), by Aerospatiale in France (ref. 4) and from some of the work conducted in the States (refs. 5 and 6) that a subjective correction is required to account for blade slap. There is very little disagreement between the results and there is a general consensus that the penalty associated with severe blade slap is 6 dB. This is illustrated in figure 4 which shows the results of psychoacoustic tests conducted within WHL (ref. 7). The figure shows the subjective correction in terms of dB(A) against a measure of the impulsive nature of the signal based on the crest factor developed by WHL some years ago (refs. 3 and 7). The subjective rating of blade slap, from none to severe, is indicated on the figure, together with a proposed correction curve. For all practical purposes, the results would be identical if, instead of dB(A), the corrections had been determined in terms of PNL values. Since the analogue crest factor method developed by WHL was proposed, NPL and Aerospatiale have developed impulsive noise descriptors which are based on digital analysis of the signals. Recently, the rating of blade slap has been reviewed by the International Standards Organization (ISO) and they have recommended the use of a method based on that originally devised by NPL (ref. 8).

The NPL and Aerospatiale CI descriptors are compared in general terms on figure 5 which shows the results for a 250-Hz sine wave pulse as a function of repetition rate. Also indicated on this figure is the true crest factor and, as can be seen, providing the integration time employed in the NPL method is small, then for all practical purposes the results of the NPL and the CI descriptor follows closely those given by the crest factor. Thus, from a fundamental point of view, there is little to choose between the methods (assuming the integration is 0.2 ms) and determination of the crest factor of the signal as originally proposed by WHL. The ISO, when it adopted the NPL descriptor, chose an integration time of 0.2 ms which is identical to the value used in the WHL analogue peak detector (ref. 9).

It is not proposed in this paper to discuss the relative merits of these methods but, since in practical terms they result in the same order of correction, to review implications which result from their use. There is, however, one exception to this general trend in that the method proposed by Galloway (ref. 6) contains a crest factor and repetition rate term and can give very different results. Firstly, the crest factor, by definition, already contains a repetition rate term and secondly, if this procedure is adopted, then helicopters with a high blade passing frequency (repetition rate) will have a high subjective penalty or correction even if the impulsive content of the signal is small (ref. 10). This result is opposite to what occurs in practice, where there is a marked tendency for the severity of blade slap to decrease with an increase in the number of blades; hence, the blade passing frequency is increased. There is a number of other difficulties associated with the use of this method and thus it would not seem to be a suitable descriptor for blade slap.

The blade slap correction was originally based on steady state (hover) recordings, although recently Aerospatiale (ref. 11) and Galloway (ref. 6) have conducted physicoacoustic tests using flyover recordings. These have shown to a first order that the steady state and flyover tests give for all practical purposes identical results. The flyovers used appear, however, in general to be of shorter duration than signals commonly encountered in the real environment. Even so, it has been argued that the results are equally applicable to hover and flyover signals.

The blade slap correction factor, as currently proposed by ISO, is added to the PNLT time history, in a similar manner to the tone correction, every half second to give the PNLT(I) time history from which the EPNL(I) is calculated using the normal approach. The difference between the EPNL(I) and the standard EPNL is a measure of the overall impulsiveness of the helicopter noise or in other words the magnitude of the annoyance associated with the blade slap.

#### Use of the Blade Slap Correction

A number of studies have been conducted within WHL on the effect of using the various proposed blade slap correction procedures. These have been based on the NPL, the Aerospatiale CI and/or the WHL analogue crest factor detector methods since, as mentioned previously, the results are essentially independent of the method used. Real helicopter and simulated helicopter signals have been used and the impact of the time at which the blade slap dies away, relative to the time of the maximum noise level, established. The general trends are illustrated in figures 6 and 7. Two cases are shown on figure 6 which gives results of a theoretical analysis. In the first the maximum correction of 6 dB, which corresponds to severe blade slap, is assumed to apply over the blade slap range whilst in the other a lower intensity blade slap with a correction of 4 dB was considered. As will be observed, the impact, as expected, of applying the correction is decreased as the time from overhead position is increased. Figure 7 shows similar results for a simulated flyover with blade slap and results of real helicopter analysis.

It is difficult from this analysis to draw specific conclusions, although, if blade slap occurs during the complete flight, the correction is more likely to be in the order of 5.5 PNdB rather than the theoretical 6 dB. From a review of a wide range of helicopters, it would appear that for the helicopter with severe blade slap on approach which "dies away" 2 or 3 seconds prior to the overhead position that the correction will be in the order of 4.5 EPNdB. Another difficulty associated with the blade slap descriptors currently being proposed by ISO is that nonimpulsive helicopters give rise to a correction in terms of EPNL of 1 to 2 EPNdB. This results from the fact that although subjectively they are not impulsive, they are more impulsive than the broadband white noise signal used as a reference in determination of the impulsive descriptor. The practical effect of this is that the difference between the impulsive and non-impulsive helicopter is further decreased.

Based on experience obtained within WHL from evaluating public reaction to helicopter noise, it seems fair to conclude, therefore, that the EPNL(I)

concept as currently being proposed still underestimates, in relation to a non-slapping helicopter, the impact of helicopter blade slap. This is not meant to imply that the correction procedure is inappropriate but rather that basic EPNL concept is inadequate.

## TAIL ROTOR NOISE

### Characteristics

Tail rotor noise, like blade slap, shows up on analysis as a series of pulses spaced at the blade passing interval. Thus, except for the differences in pulse frequency and blade passing frequency, the signals, which subjectively are classed "whine", are very similar to those associated with blade slap. This is illustrated diagrammatically in figure 8 which shows representative blade slap and tail rotor noise pulse chains. Thus, from a rating point of view, tail rotor noise is impulsive in character and hence "rated" by the various blade slap descriptors discussed previously. This is a very important point which is overlooked by many investigators who simply associated tail rotor noise with a discrete frequency spectrum.

### The Tone Correction Procedure

Tail rotor noise, as discussed previously, is very dominant on approach, but unlike blade slap, it dies away well before the overhead position, as illustrated in figure 3. When tail rotor noise is pronounced, then it can be detected on a one-third octave band plot; a typical result is shown on figure 9. The EPNL procedure is, however, relatively insensitive to such tones as can be seen from results indicated on the figure. If the flyovers shown in figure 3 are examined, then it can be shown that the EPNL for the Scout with the high level of tail rotor noise is only 2 EPNdB higher than that for the Wessex. Part of this is due to the difference in the duration correction arising from the slightly different flight speeds between the two helicopters. If this is taken into consideration, then the calculated difference is less than 1 EPNdB. In an attempt to highlight this problem further, the equivalent continuous noise level ( $L_{eq}$ ) has been calculated for a Scout flyover when the tail rotor noise is very pronounced and compared with the prediction of the  $L_{eq}$  for an equivalent flight with no tail rotor noise. This is illustrated in figure 10 and it will be noted that the tail rotor 'hump' is within 3 dB(A) of the maximum dB(A) level. The difference between the two  $L_{eq}$  values, based on the levels within the region covered by the 'maximum - 25 dB(A)', is 1.9 dB(A) - yet obviously the two conditions sound very different.

When analysing flyover signals, it has also been observed that tone corrections result in a constant difference between the PNL<sub>T</sub> and PNL values, being typically 1.5 dB. Owing to the variability of the one-third octave band spectra, the band which is responsible for the correction does not appear to be representative of the real situation. This is considered to be due to the complex nature of helicopter noise.

It is concluded therefore from the analysis outlined above and detailed reviews of a wide range of flight conditions that tone corrections in the EPNL procedure bear little relation to the true annoyance of helicopter tail rotor noise.

#### Rating by Impulsive Noise Descriptors

Since tail rotor noise takes the same form as blade slap, then any impulsive descriptor will be equally sensitive to both of these sources of noise and, of course, to any other impulsive sources of noise. This can be seen on figure 5 which, in addition to values for idealised blade slap pulses (low repetition rates), shows results for idealised tail rotor noise. As discussed previously, values are shown for the NPL (ISO) and Aerospatale CI descriptors and the crest factor. The main difference between the two sets of results is that whereas the NPL (ISO) method gives a measure of blade slap when an integration time of 10 ms is used, it effectively rejects tail rotor noise. This effect can be better appreciated from the plot for idealised signals shown in figure 11. It may appear from these plots that if a 10 ms integration time was used, then tail rotor noise would be rejected and the measured value in practice would depend solely on the level of the impulsive (blade slap) noise. There are, however, a number of major objections to this. Firstly, the relationship between the NPL descriptor ( $10 \log I$ ) and the crest factor varies with repetition rate - in other words, on figure 5, the values are not parallel to those of the crest factor. More importantly, however, is the fact that use of such a method would give a result independent of the pulse frequency, and hence crest factor, as indicated in figure 12. Thus, such a solution is not practical.

In the method originally proposed by WHL for rating blade slap, which was based on the use of the crest factor, this problem was overcome by passing the signal through a band pass filter centered on 250 Hz in order that all impulsive signals except those associated with blade slap were rejected (ref. 3). Such a method is used within WHL for assessing the magnitude of blade slap, but objections were raised against this method on the grounds that since the widest standard filter which could be used was an octave band (177 to 354 Hz), some helicopters could generate blade slap with the main energy above the upper frequency limit. An example often quoted is the Bolkow BO 105 which appears to have the blade slap energy maximum centered on 600 Hz (ref. 12), while on most other helicopters it is around 250 to 300 Hz (ref. 13). It is considered that the WHL proposal could possibly be further developed to take account of such cases and it is questionable whether a signal with a repetition rate, as is the case of the BO 105, of 28 Hz and "pulse frequency" of 600 Hz will subjectively sound the same as the blade slap generated by other helicopters. It has also not yet been shown whether the standard PNL/dB(A) method fails to penalize such blade slap in a similar manner to that found for blade slap of the type used in the studies summarized in figure 4. WHL has, however, not pursued this method recently since current proposals by ISO provide an adequate descriptor for blade slap and there is an intuitive feeling - recently confirmed by preliminary subjective tests - that the ISO method could be used to account for both tail rotor noise and blade slap.



If figures 5 and 11 are examined in detail, it will be observed that the crest factor associated with tail rotor noise is less than that for blade slap. This is a genuine effect and agrees well with the real practical situation in that severe blade slap is always more pronounced and annoying than the corresponding high level of tail rotor noise.

### Subjective Evaluation

Preliminary psychoacoustic tests have been conducted within WHL using simulated and real helicopter steady state (hover) recordings (ref. 14). The results obtained to date are shown in terms of dB(A) values in figure 13. This figure is directly comparable to the blade slap results shown in figure 4 and, as will be noted, it suggests that pronounced tail rotor noise requires an additional correction of 4 dB(A). It follows that, to a first order, this is similar to blade slap and therefore, by taking into account that tail rotor noise gives slightly lower crest factor than associated with blade slap, it can be argued that an impulsive descriptor of the type proposed by ISO can adequately account for both sources of impulsive noise. If this approach was adopted, then obviously the conventional tone corrections would not be required. The impulsive rating procedures, as currently envisaged, have a 'cut off' at around 2 kHz and the level of tail rotor noise is very low above 1 kHz. It would seem appropriate, therefore, to limit the tone correction procedure in the present EPNL procedure to, say, 1 kHz and above. This would provide, assuming an impulsive noise descriptor was used, a good measure of both sources of impulsive noise, while ensuring that high frequency discrete tones from the engine etc. were adequately covered and that tail rotor noise was not penalized twice.

### THE REQUIREMENTS FOR NOISE STANDARDS

From the experience within the UK it would seem reasonable to assume that the aim of 'noise certification' should be, in general, to contain the current situation since, unlike CTOL aircraft, helicopters do not cause any major noise disturbance. There are, of course, a number of noisy helicopters which are exceptions to this general rule and hence 'certification' limits should be such as to prohibit their development and ensure that they are phased out of civil use. Even so, there does not appear to be any case for setting standards which would require a dramatic reduction in the noise generated by the majority of helicopters.

The helicopters in the subjectively 'noisy' category are usually those which generate high levels of 'blade slap' (impulsive main rotor noise) or to a lesser extent those with a high level of tail rotor noise. It has been established that the standard dBA and PNL (PNdB) units do not adequately account for blade slap and 'corrections' are required. The position relating to the subjective impact of tail rotor noise has not been studied in such depth, but it appears from the available evidence that the standard procedures do not fully quantify this source even if the 'tone correction procedure' in the EPNL procedure is applied. It follows, therefore, that it is completely false to

use a unit which does not take these aspects into account when setting the appropriate limit.

Noise certification is an important issue and it is vital that care should be taken in both the selection of the flight test conditions and the rating unit since certification will have a long term effect on the helicopter industry and the community. It seems essential that a method and a rating unit which takes into account the subjective impact are derived or otherwise public reaction will be based on the feeling that certification is inadequate and then numerous local rules will be applied. These could be more severe than the certification requirements and the industry would be burdened by the need to meet conflicting requirements. It is, therefore, considered that the certification scheme should be based on a full technical evaluation of all the issues involved including those outlined in this paper.

#### CONCLUDING REMARKS

Helicopter noise is not the major problem often suggested, although obviously there are a number of noisy helicopters which give rise to complaints. Thus, it would appear that although there is a need to limit, and possibly lower slightly, the noise levels associated with current helicopters, there is little justification in attempting to obtain a dramatic reduction. This is particularly true if the economic penalties involved in obtaining noise reductions on helicopters and the likely gains in real noise terms in a real environment are taken into account. Furthermore, it would appear from the experience of WHL that many of the problems that occur in practice are associated almost entirely with blade slap and/or high levels of tail rotor noise which occur on approach during cruise flight. In simple terms there is ample evidence to suggest that a blade slap correction is required and that when the blade slap is severe, this should be 6 dB. A similar situation occurs in the case of the tail rotor noise and although preliminary results indicate this can be tackled in a similar manner to blade slap, it is recognized that it will be some time before such a correction is accepted. The main problem appears to be, however, that if these corrections are taken into account on a "half second" basis, then since the rating methods are being based on the EPNL concept, they will not account for the annoyance caused by helicopters in practice. There is also the possibility that even if certification results in a reduction of the maximum noise emitted by a helicopter during flyover, the character (crest factor) of the noise generated on approach due to blade slap and/or a high level of tail rotor noise will remain the same. Thus, it is possible that the annoyance to the public will, for all practical purposes, be the same even though the absolute level is reduced. Added to this is the fact that near a heliport transient manoeuvre noise (bank turns, etc.) may still occur and since to some extent these are independent of the maximum noise generated by the helicopter, the impact of noise certification in this case may again be small. This particular aspect can, however, be controlled in practice by local heliport or ATC rules.

A review has been made of possible alternative methods of rating helicopter noise and to date WHL freely admits that it has not yet been able to

devise a completely acceptable scheme. Aspects considered have included, in the EPNL procedure, changing the calculating time to the 'maximum level - 20 dB' but this does not give any marked improvement and a method in which a correction based on the crest factor of the signal in the far field (approach condition) is added to the computed PNLM or EPNL value. Use of the Leq concept has also been evaluated, together with a number of 'ad hoc' approaches where different allowances have been taken into account for blade slap and/or tail rotor noise.

Since there is obviously difficulty at the present time with the overall rating procedure to be used, this again gives support to the view that certification should essentially provide a scheme which limits the use and development of very noisy "slapping" type helicopters or those with high levels of tail rotor noise, rather than attempt an overall reduction of helicopter noise. In this context it is also worth noting that the prediction of 'total helicopter' noise is relatively inaccurate and less precise than commonly associated with fixed wing aircraft. This is understandable since the research effort both in terms of manpower and financial resources has been significantly less than in the case of CTOL aircraft. The main sources of rotor noise are, however, relatively well understood and it is the interaction effects which cause problems during predictions. It also implies that the configuration (layout) of the helicopter has a significant impact in the resulting overall noise. It follows, therefore, that it is not possible to design, within the required accuracy, to a specific level.

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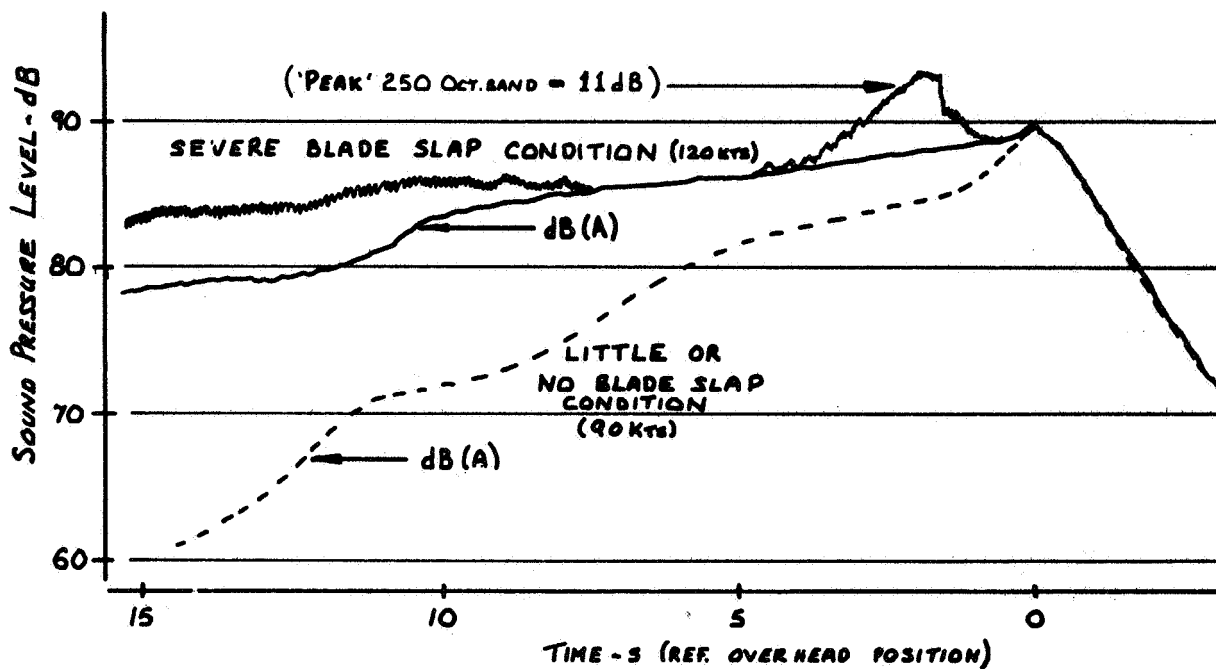


Figure 1.- Flyover time history - 2 bladed main rotor helicopter (UH-1B).

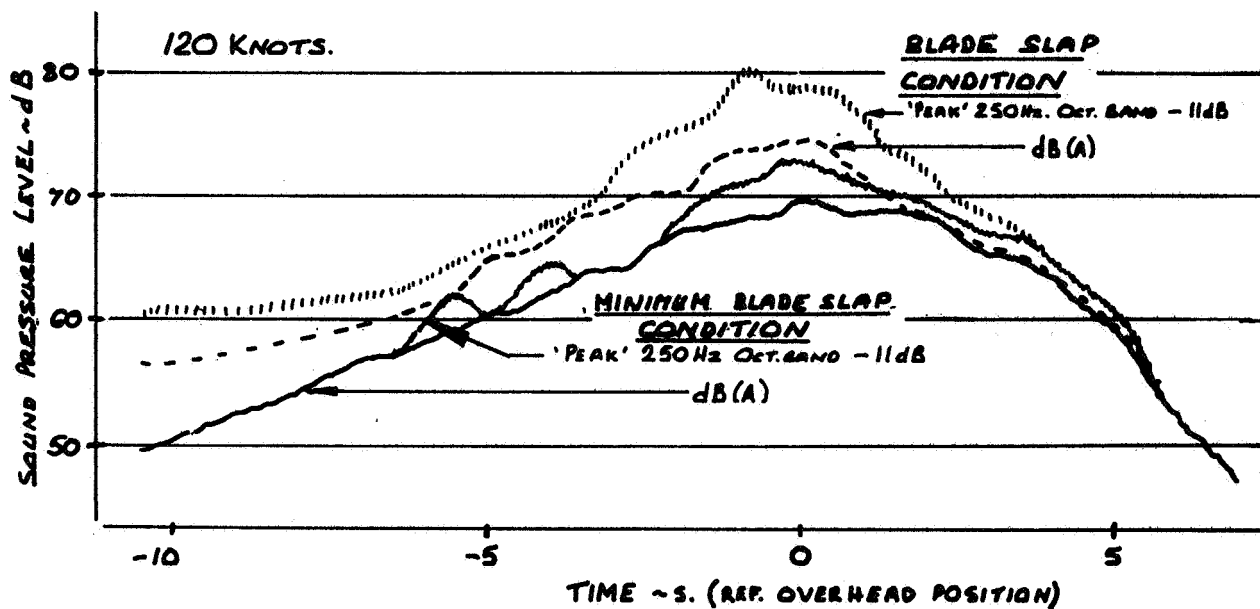


Figure 2.- Flyover time history - tandem rotor helicopter (V107).

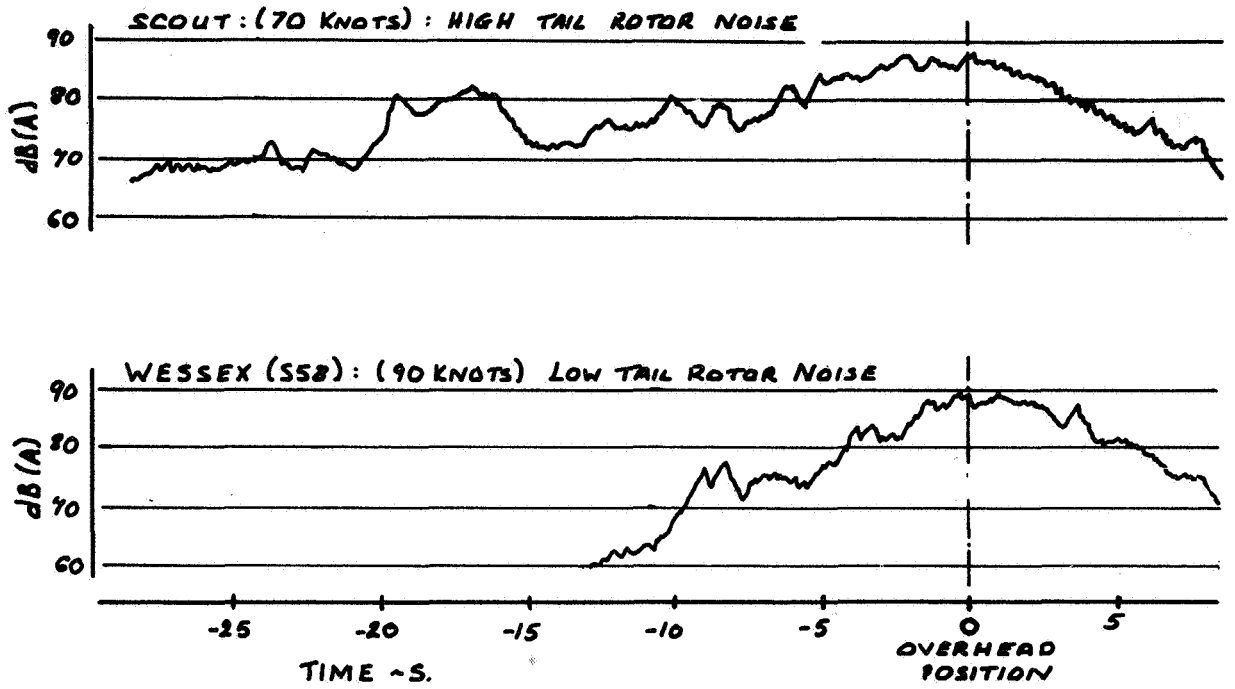


Figure 3.- Flyover time history - Scout and Wessex.

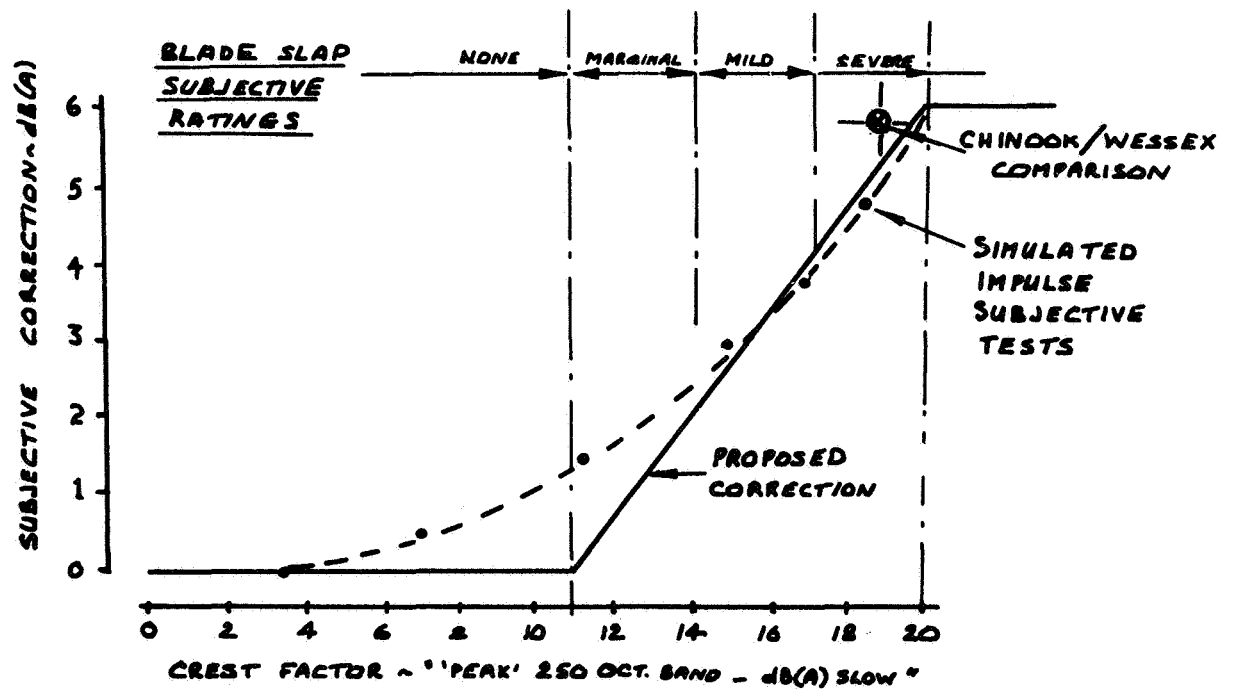


Figure 4.- Blade slap: subjective correction.

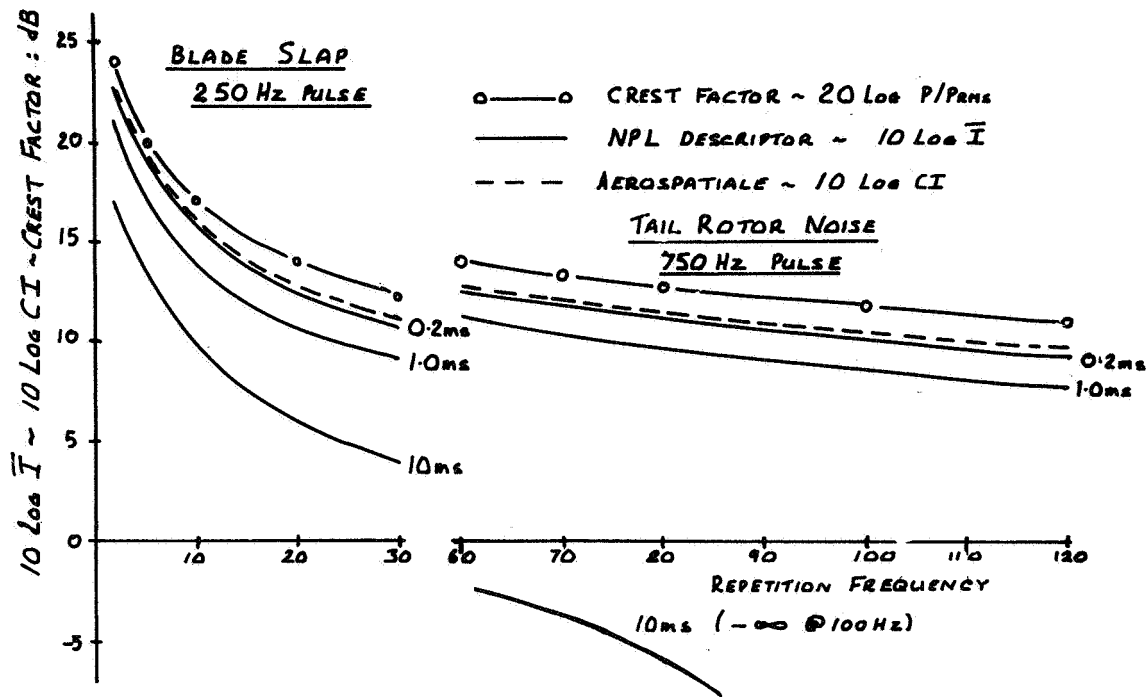


Figure 5.- Characteristics of impulse descriptors - variation with repetition rate.

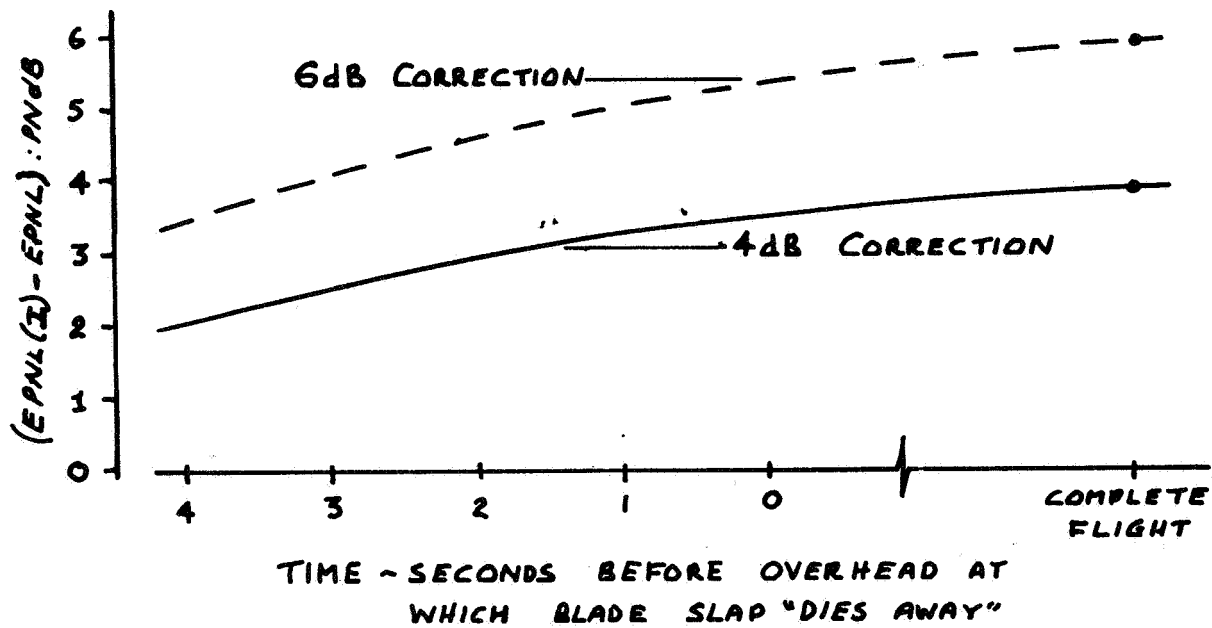


Figure 6.- Impact of blade slap descriptors on EPNL (idealised signals).

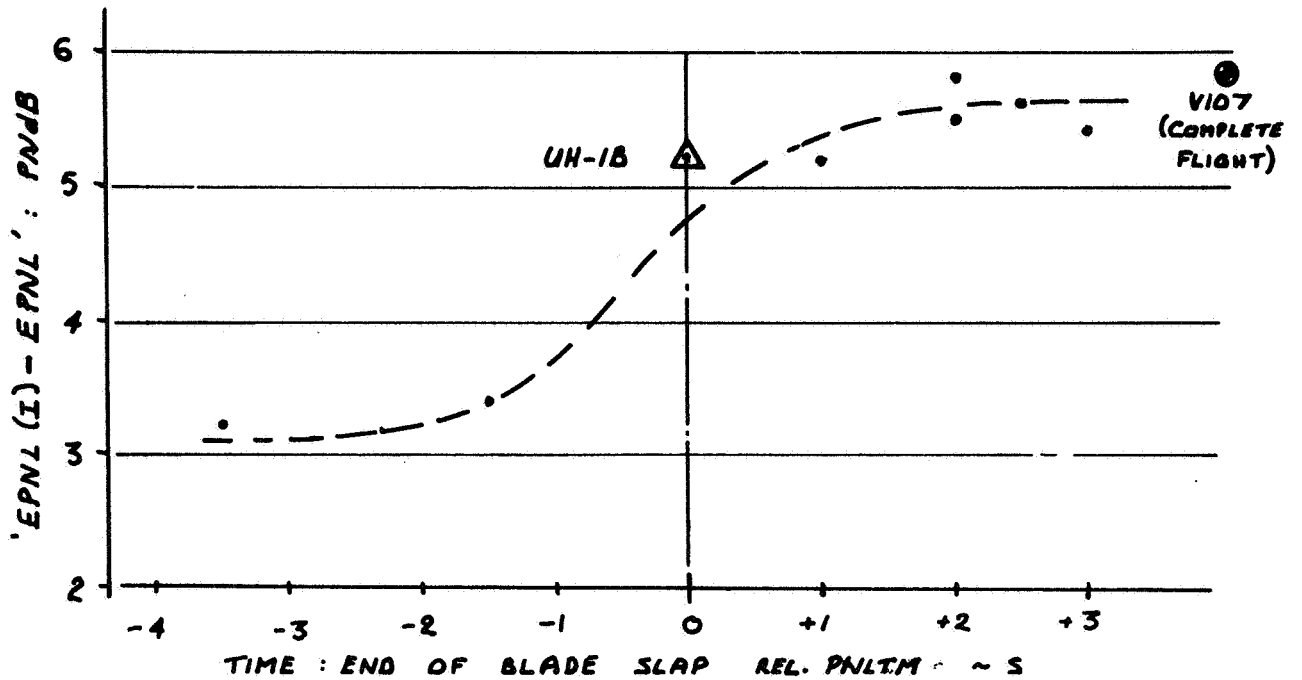


Figure 7.- Impact of blade slap descriptors on EPNL - simulated and real helicopter results.

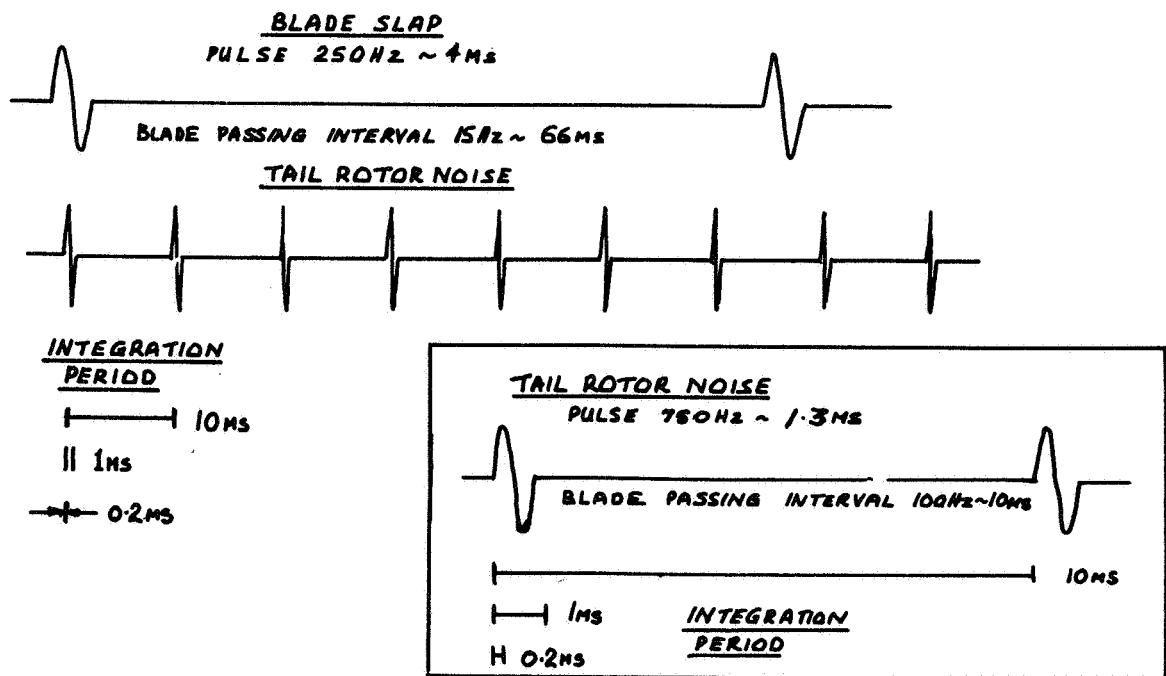


Figure 8.- Diagrammatic representation of blade slap and tail rotor noise.



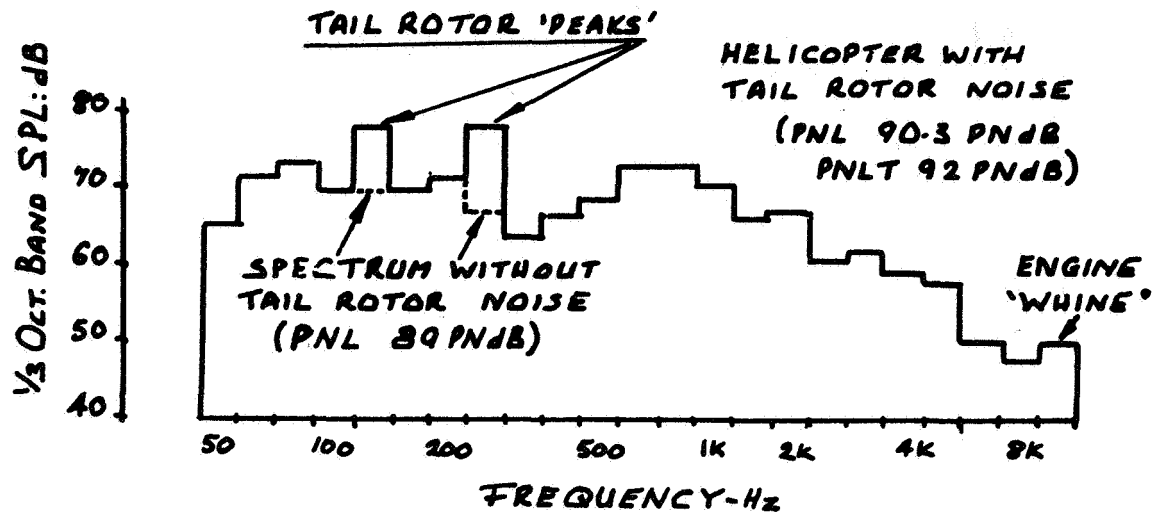


Figure 9.-  $\frac{1}{3}$  octave band of helicopter noise.

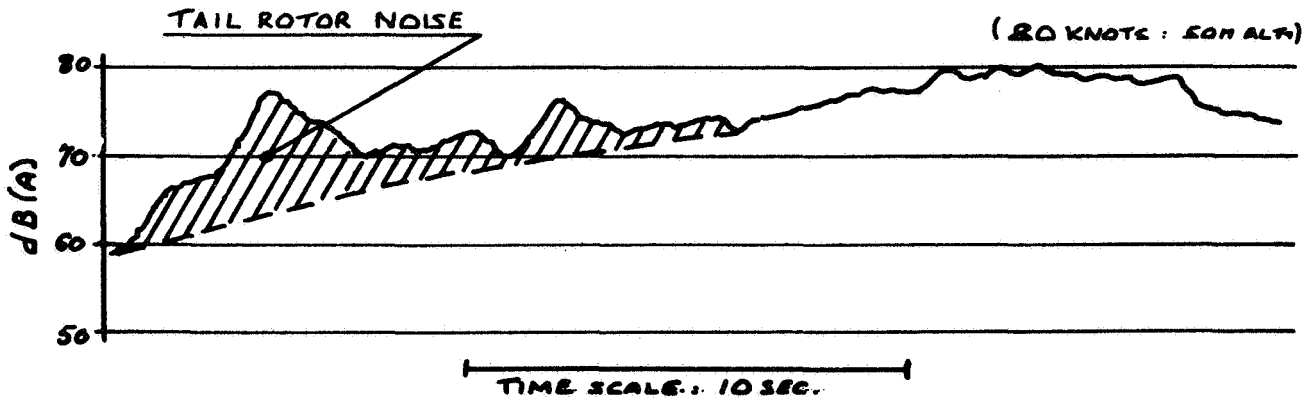


Figure 10.- Flyover time history. Scout helicopter with high level of tail rotor noise.

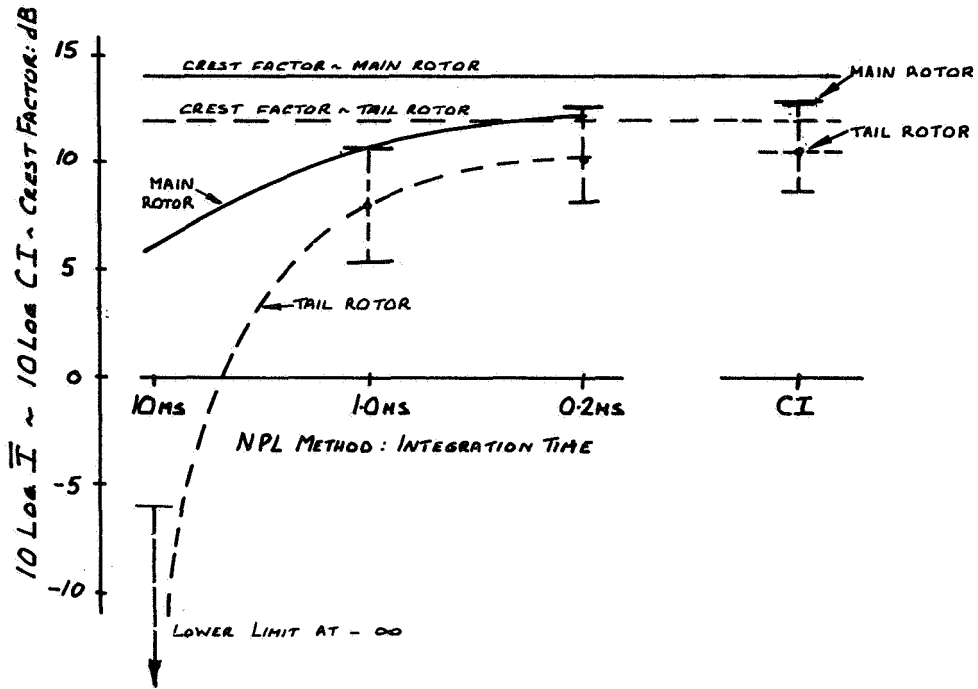


Figure 11.- Variation of main and tail rotor noise with integration time and descriptor.

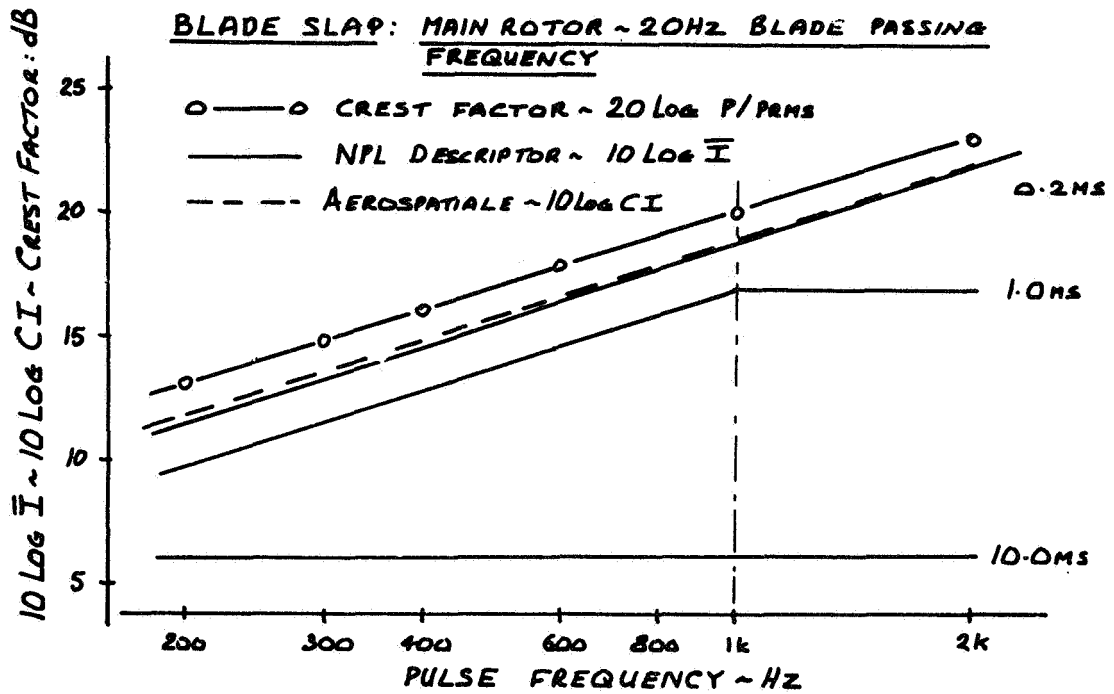


Figure 12.- Characteristics of impulse descriptors - variation with pulse frequency.

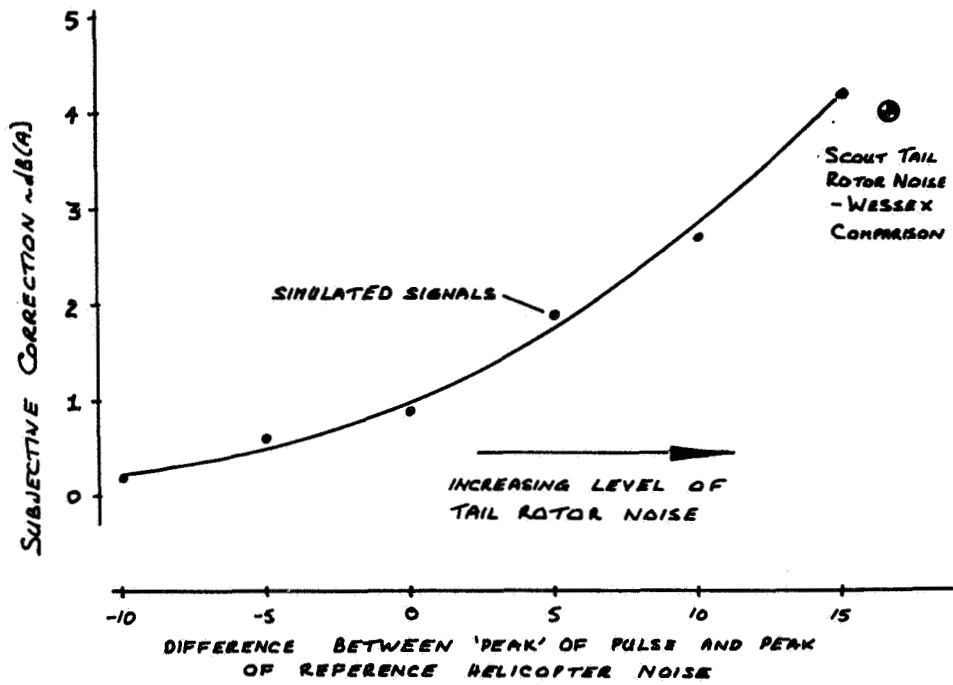


Figure 13.- Tail rotor noise. Subjective correction - preliminary results.