Proceedings of The Institute of Acoustics

HELICOPTER EXTERNAL NOISE LIMITS - A PROBLEM OF DESIGN

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INTRODUCTION

After many years of discussion within the International Civil Aviation Organisation (ICAO) helicopter noise certification is now becoming a reality. Thus, manufacturers will be required to demonstrate under controlled conditions, compliance with maximum permitted noise levels as part of the airworthiness trials. Failure of a new aircraft type to meet the statutory noise limits will preclude the issue of a Certificate of Airworthiness.

In the case of jet powered fixed wing aeroplanes, already subject to noise certification, considerable reductions in external noise were obtained by the progressive introduction of high by-pass ratio turbo-jet and more latterly, turbon-fan engines. More significantly perhaps, modern turbo-fan engines are not only quieter than their predecessors but also offer greater performance and more economical operation. In contrast, the development of compact, powerful gas turbine power plants although enabling improvements in helicopter performance in terms of speed and payload has not resulted in noise reductions. This is because the move from reciprocating to turbine engines together with exploitation of increased installed power has resulted in the sound of helicopters being generally characterised by rotor noise. This of course means that the option of reducing noise by engine noise improvements is not available or is at best, of limited value.

Significant reductions in noise levels after the first flight of a new helicopter type are likely to necessitate: (i) A loss or at least a change in performance and / or (ii) An escalation in development costs which may at worst include major redesign.

The first of these will probably be unacceptable to both military and civil customers alike, whilst in todays industrial and financial climates, the second may well result in dire consequences for the manufacturer.

Clearly, major aircraft programmes cannot be jeopardised by a hit and miss approach to noise and it is, therefore, essential that the helicopter designer be able to estimate the expected noise levels and characteristics of a new design with a reasonable degree of accuracy. Such methods must be sensitive enough to enable detailed parametric studies to be carried out and permit trade-off and performance penalties to be studied in detail.

This paper discusses the implications of noise certification and explains why noise issues must feature at the design stage.

HELICOPTER EXTERNAL NOISE

As explained in the introduction, in most cases the dominant sources of external noise originate from the rotor system. Rotor noise has been the subject of much discussion in the literature; here only a general review of the salient features is appropriate. Considered in isolation, noise radiation from a helicopter rotor takes the form of rotational noise harmonics of the blade passage frequency and broadband noise. The shape of the harmonic spectrum and the relative strength of the broadband noise content depend on a number of design parameters, the most important being Tip Mach No., blade loading and the number of blades per rotor. In addition, the sources are directional, the rotational components being radiated strongly in the direction of motion, particularly at high flight speeds, while broadband noise radiates most strongly along the rotor axis. The overall noise signature of a helicopter will, of course, depend on its configuration which can be of either the main and tail rotor type, or the two main rotor type where the rotors may be disposed in tandem, co-axial, intermeshing etc. In this context it is important to distinguish between those noise sources inherent in the operation of the rotors and those caused by aerodynamic interaction between rotors and by installation effects – tail rotor fin blockage etc. This is particularly true for tandem rotor helicopters on which overlap of the rotor discs results in strong interactions between blades and vortices. Such interactions produce a highly impulsive noise, readily identifiable and clearly audible over several miles. A similar effect can be observed on most helicopters during certain manoeuvres such as banked turns and landing approaches. Here the impulsive noise known colloquially as 'blade slap' occurs if vortices shed by the main rotor blades remain in or close to the rotor disc plane. This condition can be of extended duration or result only momentarily depending as it does on rate of descent and / or disc attitude. Whatever the cause, whether as a direct consequence of design or as a result of flying technique, blade / vortex interaction noise will, in the worst case, dominate over all other noise sources. The net result is that the aerodynamic system should be considered as a whole rather than as separate components if the true noise characteristics of a design are to be established accurately.

HELICOPTER NOISE CERTIFICATION

The development of noise testing procedures, units of measure and maximum permitted noise levels is the responsibility of the ICAO Committee on Aviation Environmental Protection (CAEP). International standards and recommended procedures are published in Annex 16 (Ref.1) to be incorporated in the relevant national standards of member states. The purpose of noise certification is inferred by the title of Annex 16 'Environmental Protection'. Incorporation of external noise limits into airworthiness requirements is a seemingly powerful method of limiting community exposure to 'noisy' aircraft. The effectiveness of such regulations in terms of community reaction, however, depends ultimately on the limits and the noise rating units chosen. First, noise limits must be a compromise between what can be achieved with available technology and what is acceptable to the majority of those exposed to the noise. Secondly, measurement units on which the limits are based must in some way reflect subjective response. This is particularly true of helicopter noise which varies not only in absolute level but differs tremendously in quality. The noise testing procedures for helicopter certification and the units chosen (EPNdB) are based entirely on those developed for fixed wing jet aeroplanes. Differences in the microphone layout and flight test programme specified result from the different operating techniques and lower noise levels involved in helicopter flying. No provisions have been made in either analysis techniques or the noise unit – Effective

HELICOPTER EXTERNAL NOISE LIMITS

Perceived Noise Level (EPNL) - to cater for the markedly different character of helicopter noise. The effectiveness of EPNL in the presence of certain pronounced characteristics of helicopter noise, primarily blade slap and tail rotor noise has been questioned for some years. Subjective tests carried out by Westland Helicopters (Refs. 2 and 3) have shown that EPNL seriously under-estimates both noise sources and suggest a correction of up to 6 EPNdB and 4 EPNdB are necessary to fully account for blade slap and tail rotor noise respectively. Although similar results have been achieved by other researchers, the problems involved in developing a workable correction procedure for EPNL are still outstanding. Until these have been resolved, ICAO re-confirm the use of EPNL as it stands and suggest reduction of impulsive noise by operating techniqies be investigated (Ref.4).

ICAO noise regulations for helicopters set maximum permitted noise levels for three test flight regimes - take-off, flyover and approach. These limits are based on the maximum certified gross take-off weight of the aircraft and allow for different noise levels during the three flight conditions. Flyover, generally considered to be the quietest condition, has the lowest limit while those for take-off and approach are 1.0 EPNdB and 2.0 EPNdB higher respectively. The certification procedure also provides for a degree of 'trade-off' enabling noise limits to be exceeded in one or two of the flight regimes if these can be 'offset' by reduced levels for the remaining condition(s). Specifically the trade-off procedure is given as follows (Ref.1):

(a). The sum of the excesses shall not be greater than 4 EPNdB.
(b). Any excess at a single point shall not be greater than 3 EPNdB; and
(c). Any excess shall be offset by corresponding reductions at the other point or points.

In summary the main points of interest are:-

EPNL does not necessarily reflect community reaction to helicopter operations.

Compliance with ICAO noise regulations does not guarantee freedom of operation. Local Authorities may impose more severe limits in sensitive areas.

The noise limits allow heavier helicopters to be noisier than lighter ones - prospective complainants may not.

Failure of current noise units to rate certain characteristics of helicopter noise may result in imposition of artifically low local noise limits which will penalise future generations of 'quiet' helicopters which do not exhibit those noise sources.

Any noise unit which does adequately rate helicopter noise will involve analysis techniques even more complex than those used to calculate EPNL. It is most unlikely that such techniques would be available.

Every attempt should be made by design (or less satisfactorily, by operating techniques) to avoid noise sources which enable ready identification of a particular helicopter type. Initial complaints will result from the ear not the sound level meter.

The flight conditions specificed for certification noise tests may not represent operating techniques used in service - there are no provisions for noise abatement procedures.

DESIGN MARGINS

It has been accepted within CAEP that the probability of meeting the noise limits should be at least 90%. In order to assess the viability of a particular aircraft two things are required. First, some method of predicting the noise levels to a known degree of accuracy must be available. Secondly, a statistical model of the certification procedure including the trade-off must be developed. Statistics are involved only because of uncertainties in noise prediction schemes and variations in measured noise levels. If noise levels can be established with absolute precision, success or failure is immediately obvious. Unfortunately noise prediction schemes are still uncertain and because of the enormity of the task involved, are likely to remain so for some time. In order to allow for errors in predictions, design margins are necessary. These may be defined as the number of EPNdB which each flight condition must be below the appropriate noise limit to achieve the desired probability. Assuming that EPNdB values are distributed normally, it is a fairly simple task to calculate probability values given the three noise levels and the standard deviations, σ associated with each. Figure 1 shows curves for σ values of 1,2, 3 and 4 EPNdB ignoring values below 50%. As might be expected, design margins need to be increased as the predicted values become more uncertain (σ increasing). Taking 90% as a minimum acceptable probability, required margins vary from 0.8 EPNdB per condition for σ = 1 EPNdB to 4.5 EPNdB for σ = 4 EPNdB. This range of design margins helps to illustrate the importance of accurate prediction methods especially considering the penalties involved. A reduction in noise level of 1 EPNdB, for example, may necessitate a reduction in main rotor tip speed of at least 20 ft/s or a reduction in cruise speed from 150 knots to 140 knots and so on.

At the present time, semi-empirical prediction methods based on fairly intimate knowledge of existing aircraft can enable a manufacturer to achieve predictions for a new design within $\pm$ 2 EPNdB. This level of accuracy, however is achieveable only if installation effects described earlier can be allowed for - noise levels for a totally new concept may be much less certain. Nevertheless, using this value as a datum, a design margin of 1.7 EPNdB per condition is required to achieve a probability of 90% as shown in Figure 1. This is a somewhat artificial situation since it would be extremely difficult to actually design an aircraft to give equal design margins for all three flight conditions. A more realistic approach is to take the noisiest flight regime - normally approach and establish the design margins required for take-off and flyover. The results are illustrated on Figure 2 which shows the effect of having maximum levels both above and below the noise limits. It can be seen that for a given maximum noise level a limiting value of probability is reached where further decreases in the other two noise levels are ineffectual. Thus, it is possible to establish the maximum probability that can be achieved simply as a function of the highest expected noise level as shown on Figure 3.

NOISE PREDICTIONS

Noise prediction methods for estimating noise levels in EPNdB for certification test conditions have been described in Westland Research Papers 624 and 654 (Refs. 5 and 6). A major limitation of the present prediction schemes is that they are only really sensitive to tip speed, thrust and blade area. When using

Leverton's method (Ref.7) to calculate rotational noise components, the number of blades is also partly taken into account by the choice of harmonic weighting values. The process of selecting one or other of the two sets of weightings as described in Ref.5 is somewhat arbitary and to some extent presupposes a knowledge of the likely noise emission. However, the results produced so far, especially in terms of EPNL are quite acceptable and the methods involved do not require enormous computing power. Nevertheless, for a true prediction method that can be employed actively during the design stage of a new helicopter project, much more subtle noise models sensitive to both geometric and aerodynamic inputs are required. In order to predict the noise levels that might be expected to result from a certification noise trial in any detail it is also necessary to account forpropagation effects encountered during the measurements. The microphone layout specified for certification exercises calls for a microphone height of 1.2 metres, resulting in considerable distortion of the measured spectra by cancellations and re-inforcements, caused by interactions between the direct wave and that reflected from the ground plane. The problems of ground reflection are well known and, therefore, it is not proposed to discuss at great length. Engineering Sciences Data Unit (ESDU) Data Item 80038 (Ref.8) contains a theoretical treatment of the problem together with the listing of a useful computer program. Attenuation of sound between source and observer due to atmospheric absorption can be taken into account using the procedures given in Ref.1.

Recent work at Westland Helicopters has attempted to replace the semi-empirical methods with mathematical models of the source mechanisms. Perhaps the most tractable of these is main rotor rotational noise. Mathematical models of thickness noise (Ref.9) and force noise (Ref. 20) have been used to calculate rotational noise spectrum for comparisons with measurements made during a trial certification noise test (Ref.11). An example of measured and predicted narrow-band spectrum levels is shown on Figure 4. In making comparisons it should be noted that the measured spectrum represents one flyover taken at random out of a group of six nominally identical runs. No attempts have been made to average the spectra or to adjust the predicted levels to achieve optimum agreement. In view of both the time varying nature of the signals and run to run variability agreement between measures and predicted levels is encouraging.

Work in this area is continuing with a view to making the models more sensitive to blade design and operating conditions. Parallel studies into blade / vortex interaction noise and broadband noise are being undertaken.

CONCLUDING REMARKS

Failure of new designs or derived versions to meet ICAO noise limits will preclude the issue of a Certificate of Airworthiness. The net result (indeed the primary objective) of noise standards will be a steady reduction in helicopter noise levels at source and a change in the subjective character by avoiding wherever possible, the more intrusive noises.

From the manufacturers point of view, the consequences of failing to meet the limits are very serious indeed and are a major incentive to develop a much better understanding of helicopter noise mechanisms. Mathematical models will enable more efficient low noise designs, improving the compromise between noise and performance.

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The opinions expressed in this paper are those of the author and do not necessarily represent the views of Westland Helicopters Limited.

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FIG.1 PROBABILITY OF CERTIFICATION AS A FUNCTION OF DESIGN MARGIN

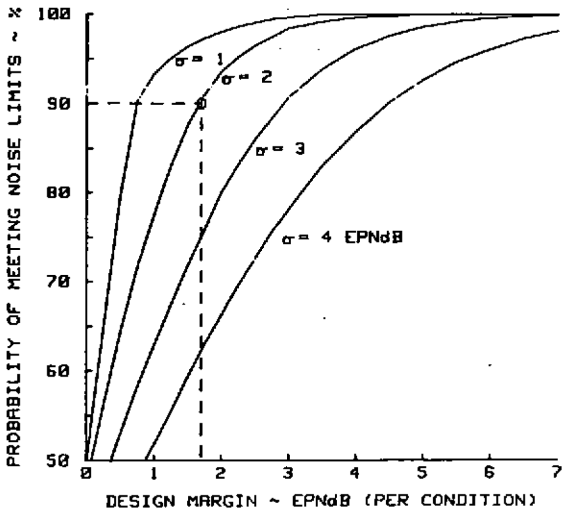

FIG.2 EFFECT OF NOISIEST FLIGHT CONDITION ON PROBABILITY VALUES

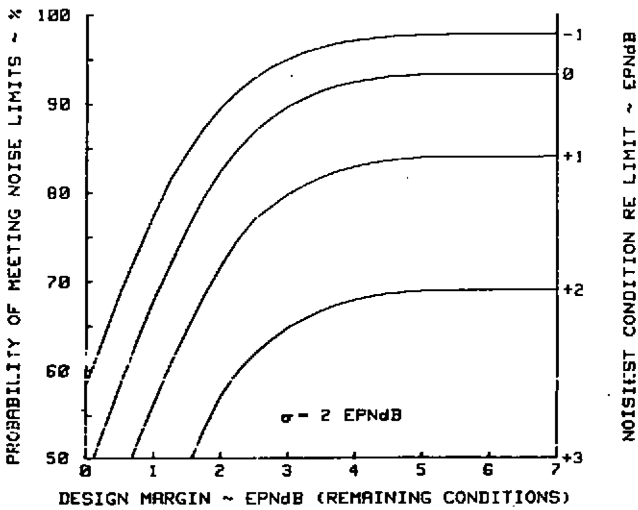

FIG.3 LIMITING VALUES OF PROBABILITY

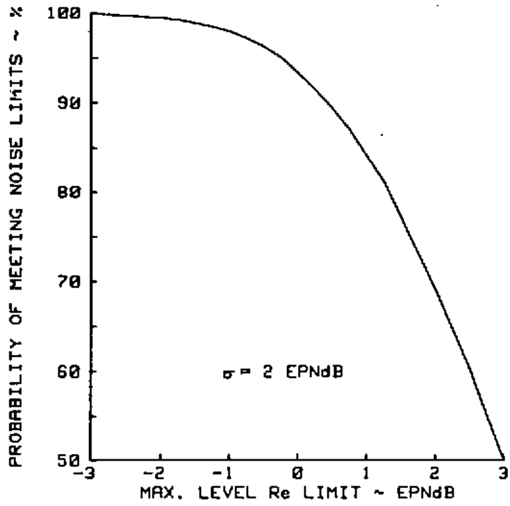

FIG.4 MEASURED AND PREDICTED ROTATIONAL NOISE LEVELS