SEVENTH EUROPEAN ROTORCRAFT AND POWERED LIFT AIRCRAFT FORUM

Paper No. 33

PRELIMINARY THOUGHTS ON HELICOPTER CABIN NOISE PREDICTION METHODS

J. S. Pollard

Westland Helicopters Limited

Yeovil, U. K.

September 8 - 11, 1981

Garmisch-Partenkirchen

Federal Republic of Germany

Deutsche Gesellschaft für Luft- und Raumfahrt e. V.

Goethestr. 10, D-5000 Köln 51, F.R.G.

PRELIMINARY THOUGHTS ON HELICOPTER CABIN NOISE PREDICTION METHODS

by

J.S. Pollard
Westland Helicopters Limited

ABSTRACT

The problems of predicting helicopter cabin noise are discussed with particular reference to the Lynx helicopter. Available methods such as modal analysis adopted for propellor noise prediction will not cope with the higher frequency discrete tone content of helicopter gear noise, with its airborne and structure borne noise contributions. Statistical energy analysis methods may be the answer but until these are developed, one has to rely on classical noise transmission analysis and transfer function methods.

1. INTRODUCTION

Helicopter cabin noise has been the subject of a number of studies over the last 5 years. These have concentrated on the noise generating mechanisms, the transmission paths between source and receiver and the noise properties of the cabin receiving space. With the advent of new helicopters, it is particularly important to be able to estimate the cabin noise environment so that the most effective noise control measures can be taken and the impact of noise on the crew can be assessed.

There are a number of problem areas associated with helicopter internal noise which make a prediction method difficult to achieve. Firstly, the different noise sources of rotor(s), engines and transmission systems all contribute to the cabin environment. Secondly, the transmission of noise to the cabin is by both airborne and structure borne paths and thirdly the noise is composed of discrete tones and broadband noise. WHL helicopters are dominated by main gearbox noise over most of the important frequency range and thus in the first instance the prediction method can be confined to this noise source only. This also overcomes the third problem (to a certain extent) since gear noise is dominated by the fundamental meshing tones and harmonics. The question of airborne noise and structure borne noise remains, however, and on the Lynx helicopter these are considered to be of equal importance.

The prediction methods normally available for fixed wing aircraft are dependant on the frequency range under consideration. For low frequency where the modal density is low, finite element analysis and coupled acoustic/structural modal analysis are used, whereas for high modal densities associated with high freuqencies, statistical energy analysis methods are preferred. In between these two frequency regions, it is not clear which methods should be used and unfortunately the helicopter situation appears to fall into this category.

This paper discusses some of the factors involved in helicopter noise prediction and examines some of the methods available and their applicability to the helicopter case. Future studies are aimed at seeing whether SEA theory can be adapted to the helicopter situation, but in the meantime effort has been directed towards reviewing the two main methods used by other helicopter investigators - namely the classical noise transmission type approach and the transfer function method. Results for the Lynx helicopter are presented and the problem areas highlighted.

2. REVIEW OF AVAILABLE PREDICTION METHODS

The most widely used method for the prediction of vehicle interior noise is modal analysis theory. When the number of modes in an acoustic cavity or surrounding structure is small, it is useful to examine the characteristics of the individual modes themselves. This was initially carried out by considering the acoustic and structural modes separately and a technique commonly applied in the automobile industry is finite element analysis. The main problems with F. E. analysis, however, are the large amount of computer storage space required for all the elements considered and the difficulty of obtaining the mode characteristics themselves before they are used to determine the cabin noise field. As an alternative approach, component mode analysis is now being used. This is where a complicated structure is split into many simpler components the modes of which are determined, and then the modes of the original structure are determined from the component modes. An obvious sub division is the structural (wall) components and the acoustic (cavity) components. Cockburn and Jolly (1) provided the basis of such an approach when they considered the modes of a stiffened cylindrical shell and its enclosed cavity and developed a boundary layer noise prediction for fixed wing aircraft.

Howlett and Morales (2) and Howlett, Williams and Catherines (3) used the formulae of Cockburn and Jolly as an initial step towards developing a prediction method for propellor driven aircraft. The modal analysis technique was applied at the low frequency region (50 - 200Hz) to give the noise reduction of the fuselage in terms of the ratio of the power spectral densities of the exterior and interior noise fields. This enabled a parametric study to be conducted to see which structural parameters were the most important. Whilst such a method was for low frequency noise only, it was a step nearer the helicopter case in that propellor noise is also characterised by discrete frequency components.

The papers mentioned so far apply modal methods to cylindrical structures and cavities. Helicopters on the other hand have more rectangular structures and different theoretical models are required. If one is considering the airborne noise path only, and since the main noise source is a gearbox situated above the cabin roof, the helicopter cabin could be modelled as a rectangular enclosure with all rigid walls except for one wall which is flexible and subjected to airborne sound. A whole series of papers on the modal analysis theories of rectangular enclosures exist in the literature (e.g. 4, 5). Most of these papers consider very small enclosures i.e panel sizes small compared to the acoustic wavelength, but once developed the theories are applied to larger enclosures. The sound pressure in the enclosure is represented by the wave equation which is solved for the boundary conditions of displacement at the flexible wall.

During recent years attention has been directed by many investigators to Statistical Energy Analysis particularly in the space craft field. This method is a useful tool for analysing systems which have high modal densities since the average quantities used are related to the energies and powers in the systems and thus the energy flow between connected structures can be determined. For the SEA method to be applied to a system, it is necessary to determine the mechanical loss factors in each sub system and the coupling loss factors between them and this is often the most difficult part of the SEA method .

3. THE HELICOPTER CASE

Modal analysis methods are essentially for low frequency noise predictions, where the modal density is low and individual modes can be considered. Statistical energy analysis methods are appropriate to the high frequency cases where the modal density is high and a diffuse field is assumed to be present in the acoustic cavity. The mid frequency region, to which helicopter gear noise applies, appears to fall between these two methods. Figure 1 shows the predicted modal count for the Lynx cabin which is approximated to be a rectangular enclosure of length 2.06 m, width 1.52 m and height 1.32 m giving a volume (V) of 4.13m^3 and a surface area (S) of 15.7m^2. Combining the axial, tangential and oblique modes in the approximate formula

$$\Delta N = \left\{ \frac{4\pi V f^3}{c^3} + \frac{\pi S f^2}{2c^2} + \frac{L f}{2c} \right\} \frac{\Delta f}{f}$$

gives the number of modes ΔN in each $\frac{1}{3}$ octave bandwidth Δf. Figure 1 shows that the number of modes increases from approximately 2.5 modes in the 160 Hz $\frac{1}{3}$ octave band to approximately 400 modes in the 1 kHz $\frac{1}{3}$ octave band. In the 500 Hz $\frac{1}{3}$ octave band, which is dominated by the fundamental of conformal gear meshing excitation of the Lynx gearbox, there are about 55 modes. Since a given enclosure contains a large number of resonant frequencies, then a single frequency sound source in the enclosure will produce a sound pressure which is the combined effect of numerous resonant systems of frequency f_n and damping constant δn. For one given resonance, the relative half width (at the 3 dB down points) is

$\Delta f_n = \frac{\delta_n}{\pi}$ and the average frequency separation between two resonances is $\frac{1}{n(f)}$ where n(f) is the modal density. Table 1 compares the values of $\frac{\delta_n}{\pi}$ and $\frac{1}{n(f)}$ for the Lynx cabin with the former based on reverberation time measurements. The results show that the damping constants vary between 20 and 40 sec^{-1} giving resonance half widths of between 7 and 12 Hz. At 400 Hz the resonance half width covers approximately 3 modes and the resulting sound pressure is made up of contributions from these 3 modes. Similarly at 500 Hz there are contributions from 4 modes. Thus in the frequency range 400 - 500 Hz it is not possible to analyse individual modes, but neither can one consider that a diffuse field is present. This leads to the criterion for a diffuse field in an enclosure known as the modal overlap method (6) in which a diffuse field is considered to be present when the modal overlap is greater than 3. The modal overlap ratio is the resonance half width divided by the average spacing between modes. This criterion is similar to the one given by the Schroeder 'large room limiting frequency' which is the frequency lower limit at which the modes in a room can be treated statistically. (7). The formula is

$f_s \simeq 2000\sqrt{\frac{T}{V}}$ and from Table 1, one can see that a typical reverberation time ($\bar{T}$) for the Lynx bare cabin is 0.23 secs giving a Schroeder frequency of around 450 - 500 Hz. It is clear, therefore, that the conformal gear meshing fundamental frequency of 446 Hz falls in the region between the modal analysis methods and SEA methods and consequently the development of a prediction method for the Lynx helicopter at this frequency becomes difficult. The higher harmonics, however, should be more amenable to the SEA method.

The importance of knowing the acoustic properties of an enclosure becomes clear when one wishes to measure the mean sound pressure level with a limited number of microphones. If, as is usual in practice, 5 or 6 microphones are used in a helicopter cabin, the data should be treated with caution and should certainly be subjected to a statistical analysis. This compares with a possible 120 microphones that could be positioned in the Lynx cabin at 446 Hz according to the formula $M = \frac{12V}{\lambda^3}$ (from reference 8). Figure 2 shows theoretically the percentage probability of the sampled mean noise levels in an enclosure lying close to the true mean noise levels for different numbers of microphones, for discrete frequency excitation above the Schroeder frequency. The results shows that with only 5 or 6 microphones there is a 90% chance of being within only $\pm$ 3 dB of the true level. If an accuracy of $\pm$ 1 dB is required, however, then the probability is less than 40% and to obtain a 90% probability at $\pm$ 1 dB the number of microphones would have to be increased to 50. This has an important bearing on test work involving soundproofing fitments etc, since, with 5 or 6 microphones, noise level changes would have to be greater than 6 dB to be genuine ones.

The following sections of this paper attempt to derive a prediction method for the Lynx helicopter gear noise and in particular concentrate on the fundamental and harmonics (1C - 8C) of conformal gear meshing. The Lynx gearbox also generates higher frequency components from the spiral bevel gear inputs but for simplicity this source has not been included in this paper. Data presented is for the Lynx 2 pinion gearbox.

4. GEAR NOISE PREDICTION AT SOURCE

Sound pressure level is not a satisfactory quantity for describing the noise emission characteristics of a machine, since it is dependent on the distance between the source and the receiver as well as on the environment in which the measurements are made. Sound power levels are essentially independent of distance and the environment and can be used to compare the noise radiation of one machine with another and, more importantly in this case, provide the basis of a prediction method. Sound power is determined by measuring the sound pressure levels over a given area enclosing the source and applying a correction factor for the environmental effects of the test room. Sound power measurements have been made of the Lynx gearbox in the test rigs and the results are shown in Figure 3 for changes in torque, rpm and spectrum harmonic number. These results are based on measurements from 8 microphones positioned on a hypothetical parallelpiped around the gearbox and some individual results are shown in Figure 4. It is clear that there is a wide scatter of data with measurement position and it has been necessary to take the average value for meaningful results . Similar variations occur with acceleration levels measured on the casing (Figure 5) and this illustrates a fundamental problem on helicopter gearboxes in that not only are there wide variations in level with measurement position but, more importantly, there are wide variations in level (up to 20 dB) between different gearboxes of the same type. Typical results for 12 gearboxes are shown in Figure 6. The reasons for these differences are not known, despite extensive studies, but it is clear that such large variations could swamp any trends that exist and make the prediction methods very inaccurate.

By averaging the data over all measurement positions, however, it has been possible to obtain reasonably accurate sound power levels from both the noise and acceleration data. The latter has been calculated by assuming that the gearbox casing can be represented by a number of simple baffled hemispherical noise sources which radiate noise independently of each other. The sound power W of each source is calculated using the formula

$$W = \frac{a^4 A_o^2 \rho c k^2 \pi}{\omega^2 (1 + k^2 a^2)}$$

Where a = radius of hemisphere (metres)
k = wave no = ω/C
A_o = surface acceleration (metres/sec^2)

and the sources summed to give the total sound power of the complete gear case. The radius 'a' of the sphere is determined by the area of casing associated with each accelerometer position. Figure 3 shows that good agreement is obtained between sound power levels (SWL) calculated from the noise data and the acceleration data.

The results of Figure 3 show that in terms of the Lynx conformal gear noise, there is approximately a 3 dB increase for doubling of torque Q(lb.ft), a 14 dB increase for doubling of rpm (or frequency f) and a 5 dB reduction for doubling of harmonic n (i.e. harmonic fall off). This leads to a power law variation of the form

$$SWL = 10 \log Q + 46.5 \log f - 16.6 \log n - 38.0$$

where f is the meshing frequency fundamental. Unfortunately this variation only applies to the Lynx conformal gear noise. Other gear noise sources will have different formulae, but it does illustrate that empirical formulae can be derived for helicopter gearboxes once measured rig data becomes available.

5. APPLICATION OF CLASSICAL NOISE TRANSMISSION ANALYSIS

If we consider only the airborne noise case at this stage, it is possible to correct the sound power levels of the gearbox at source for the transmission loss of the cabin roof and the receiving space effects of the cabin to obtain the cabin sound pressure levels. This method has been used by other investigators (9) but is subject to a number of errors because, although the cabin receiving space effects can be assessed fairly accurately, it is necessary to make assumptions regarding the noise field between the gearbox and the cabin roof.

It is firstly assumed that all the airborne noise reaching the cabin is mainly radiated by the bottom surface (area S) of the Lynx gearbox which is taken to be a rectangle of size 1.05 metres x 0.75 metres. By dividing this surface up into a number of equal incoherent simple point sources radiating into one hemisphere, the sound pressure level at a point from the surface is given by

$$SPL = SWL - 10 \log S + 10 \log C_1$$

where C_1 is a correction term which takes account of the source directivity effects, and the distance from the surface. (both near field and far field). Using the curves of Tatge (10) and taking the distance from the base of the gearbox to the roof as 0.15 metres, the sound pressure level SPL_1 external to the roof was calculated. Transmission loss values for the roof panels were then applied to give the sound pressure levels SPL_2 just inside the roof. These values are converted back to sound power levels using the expression

$$SWL_2 = SPL_2 + 10 \log A$$

where A is the area of the roof. Finally the average sound pressure levels in the cabin are given by

$$SPL_{average} = SWL_2 - 10 \log A + 10 \log (C_2 + 4/R)$$

where C_2 is a correction term which takes account of the direct field in the cabin and 4/R is a correction term for the cabin reverberant field. Since the term 10 log A cancels out in this analysis it is not necessary to know the area of the cabin roof.

The individual steps for the Lynx conformal gear noise are shown in Table 2. The cabin roof transmission loss values are based on single panel measurements performed in the WHL reverberation facility (11) but since the cabin roof of the Lynx helicopter has a number of holes in it for control runs, cables, access points etc, it has been necessary to reduce the T.L. values accordingly. In fact, a reduction in T.L. corresponding to a 5% hole area was used. In deriving the noise field between the gearbox and the cabin roof, only the direct/near field has been calculated, unlike the engine noise example given in reference 9 where a reverberant field has been included caused by reflections from the engine cowling. In the Lynx case it was felt justified in ignoring the reverberant field since the distance of 0.15 m between the gearbox base and cabin roof is much less than the acoustic wavelength of 0.7 m at 500 Hz. It is not until a frequency of 2 kHz is reached before the wavelength becomes of the order of 0.15 m and thus it is possible that above 2 kHz it may be necessary to consider the reverberant field contribution.

Table 2 shows the predicted cabin noise levels compared with measured values averaged over 4 microphone positions and over 3 different Lynx helicopters during flight. Comparing measured and predicted cabin noise levels quite good agreement is obtained at all frequencies. Also in Table 2 are actual noise levels measured in the space between the gearbox and cabin roof and again quite good agreement is obtained with the predicted values. Obviously the measured cabin noise levels could contain a structure borne noise contribution which can not be assessed at this stage. It is also conceivable that there is a structure borne noise contribution in the noise above the cabin roof, but since this area is so close to the gearbox it is likely to be dominated by airborne noise. If a reverberant field contribution had been included in the calculation of the noise levels between the gearbox and the cabin roof, then an additional 9 dB would be added to the predicted noise levels, thus making them unrealistic. The value of 10 log $(C_2 + 4/R)$ for the cabin noise field was 2.5 dB and was controlled by the reverberant field.

With regard to the prediction of structure borne noise, a suitable method has not yet been developed. Reference 9 divides the cabin surfaces up into radiating areas and relates the radiated power of each surface to the dominant roof area. It appears to assume, however, that all the acoustic power associated with the gearbox is transmitted via the gearbox feet to the cabin structure. This means in fact that the airborne noise path has been considered negligible, but it is difficult to see how such an assumption can be justified.

6. APPLICATION OF TRANSFER FUNCTION METHOD

Since the helicopter cabin noise is likely to have both airborne and structure borne noise contributions, the obvious method of tackling the problem is to subject the helicopter to acoustic and vibratory excitation separately and measure the response in terms of cabin noise levels and structural acceleration levels. There are, however, practical problems involved since it is difficult to excite the structure (either acoustically or vibrationally) during ground tests in the same manner as would occur in flight.

In theory it should be possible during static tests with a vibration input to relate the noise levels at a cabin microphone to the acceleration level at a gearbox foot i.e. determine a transfer function. In this way it should be possible to apply the transfer function to measured in flight acceleration levels to compute the in flight structure borne cabin noise level. A similar procedure should be possible with airborne noise excitation. Such methods have been explored by other investigators in reference 12.

Taking the airborne case first, an experiment was conducted on the Lynx helicopter in which a small loudspeaker was mounted in the central shaft near the base of the gearbox and the noise levels were measured inside the cabin and in the space between the gearbox and cabin roof. Figure 7 shows the noise reduction between the two regions, the measured noise levels beneath the gearbox and the predicted cabin noise levels. Comparing the predicted cabin noise levels of Figure 7 with the measured values of Table 2, the agreement is quite good at high frequency but poor at the lower frequencies (1C - 4C). The experiment appears to have been an unsatisfactory one in that the differences in level between the cabin microphones and the gearbox microphone do not vary with frequency whereas in reality they should approximately reflect the transmission loss of the cabin roof which should increase with frequency. The reason for this is likely to be that the loudspeaker excitation was not giving the correct representation of the in-flight situation.

The structure borne noise case is considerably more complicated both in terms of conducting the correct experiment and interpreting the results. The problems evolve around the form of excitation and the frequency bandwidth to be used. In the first case the gearbox feet have forces in the vertical, lateral and fore/aft directions and measurements in flight have shown similar acceleration levels in all three directions at all four feet. In order to obtain reliable transfer functions, it is necessary to excite the structure in a similar manner during the ground tests and, on the experiments conducted to date, this has proved extremely difficult to perform. Initially a Lynx helicopter was subjected to a vibratory excitation by a vibrator attached firstly to the port forward foot (vertical input) and secondly the aft starboard foot (vertical input). Whilst these tests gave representative acceleration levels at the foot being excited, the other three feet were obviously receiving much smaller inputs, thus giving a distorted picture of the helicopter noise/acceleration response. A second set of experiments was conducted in which the helicopter was excited at the rotor head area in the lateral and fore/aft directions in turn. These tests again tended to produce a non uniform response and in addition the vibrator had insufficient power to excite the structure to realistic acceleration levels. Ideally three vibrators are required at each foot to give the most representative response in all directions.

The question of frequency bandwidth also proved difficult to resolve. In order to detect resonances of the structure, a swept frequency vibratory input was used. Typical results are shown in Figure 8 and it is clear that a large number of resonances exist throughout the frequency range. Obviously some sort of averaging process is required over defined frequency bandwidths to derive the transfer functions, but such a process becomes difficult to correlate with the discrete frequency excitation experienced in flight.

Studies are continuing to resolve these important issues of experimental and analysis techniques and to devise a method of combining the data from the four sets of experiments to produce an averaged result. In the meantime it is clear that the predicted cabin structure borne noise shows wide variations in level depending on which set of ground test data is used to derive the transfer functions. Figure 9 illustrates the possible band of predicted levels and compares then with the measured data. Since generally all four forms of vibration input give predicted cabin noise levels greater than the in flight measured levels, the prediction method is obviously incomplete and the whole aspect of the transfer method requires further careful consideration.

7. CONCLUDING REMARKS

The paper has attempted to highlight some of the problem areas connected with helicopter cabin noise prediction and has considered specific aspects relating to the Lynx helicopter.

In summary the modal density of the cabin receiving space at gear frequencies is to high for modal analysis methods and is likely to be more amenable to statistical energy analysis methods. The conformal gear meshing fundamental may prove troublesome, however, since it falls in the frequency range between the two methods.

Measurements obtained in the gearbox test rigs have enabled empirical formulae to be developed for the sound power levels of the Lynx conformal gear noise in terms of torque and rpm variation and harmonic fall off. Based on these formulae it has been possible to convert the sound power levels at source to predicted airborne noise levels in the cabin using standard noise transmission theory. Good agreement has been obtained with measured data, although obviously certain basic assumptions have been made in the method.

The transfer function method, however, has to date not proved satisfactory. Whilst airborne noise was underpredicted, the structure borne noise was vastly overpredicted. The reasons for this are still under investigation and may be associated with experimental technique or data interpretation. The issue of whether airborne noise or structure borne noise dominates the Lynx cabin noise has, therefore, still not been resolved.

It is clear, however, from all the noise investigations conducted to date, that variability of test data is an important and fundamental issue affecting all the prediction methods, and in future all measured data should be treated with caution and subjected to a statistical analysis.

8. ACKNOWLEDGEMENTS

The author wishes to thank his colleagues in the Acoustics Department and the Theoretical Studies Department who have provided invaluable assistance in the preparation of this paper. The Ministry of Defence is also acknowledged for giving permission to publish the data much of which was obtained under MoD Contracts.

9. REFERENCES

1. J. A. Cockburn, A. C. Jolly - Structural - Acoustic Response, Noise Transmission Losses and Interior Noise Levels of an Aircraft Fuselage Excited by Random Pressure Fields. Air Force Flight Dynamics Laboratory Report AFFDL - TR - 68 - 2

2. J. T. Howlett, D. A. Morales - Prediction of Light Aircraft Interior Noise NASA TMX - 72838 April 1976

3. J. T. Howlett, L. H. Williams, J. J. Catherines - Measurement, Analysis and Prediction of Aircraft Interior Noise. AIAA Conference, California 1976

4. W. McDonald, R. Vaicaitis, M. K. Myers - Noise Transmission through Plates into an Enclosure. NASA TP 1173, 1978

5. R. Vaicaitis, M. Slazak - Noise Transmission through Stiffened Panels J. of S and V 70(3) pp 413-426 1980

6. R. H. Lyon, H. G. Davies - Statistical Energy Analysis for Designers Part II. The Engineering Application AFFDL - TR - 74 - 56 Sept 1974

7. H. Kuttruff - Room Acoustics. Applied Science Publishers Ltd., 1979

8. L. L. Beranek - Noise and Vibration Control Mc. Graw - Hill Book Company 1971

9. L. S. Levine, J. J. DeFelice - A Practical Approach to Helicopter Internal Noise Prediction. Specialists Meeting on Helicopter Acoustics NASA Langley, Virginia May 1978

10. R. B. Tatge - Noise Reduction by Plane Arrays of Incoherent Sources. J.A.S.A. Vol. 52, 1972, pp 732 - 736

11. S. Owen - Laboratory Evaluation of Vibrating Panel Treatments. Part I. WHL Research Paper 622. May 1981

12. B. Murray, J. Wilby - Helicopter Cabin Noise - Methods of Source and Path Identification and Characterisation. NASA Langley Helicopter Noise Symposium May 1978

TABLE 1 RECEIVING SPACE PROPERTIES OF LYNX CABIN

$\frac{1}{3}$ OCT. FREQ.	Δf	λ (METRES)	REVERB. TIME (secs)	δ_n (sec^{-1})	$\frac{\delta_n}{\pi}$	ΔN	n(f)	1/n(f)
125	29	2.7	0.18*	38.4	12.2	1.3	4.48×10^{-2}	22.3
160	37	2.1	0.26*	26.6	8.5	2.5	6.76×10^{-2}	14.8
200	46	1.7	0.30*	23.1	7.4	4.5	9.78×10^{-2}	10.2
250	58	1.3	0.30*	23.1	7.4	8.5	14.7×10^{-2}	6.8
315	73	1.1	0.18	38.4	12.2	15	2.05×10^{-1}	4.9
400	92	0.85	0.21	32.9	10.5	30	3.26×10^{-1}	3.1
500	115	0.68	0.23	30.0	9.5	55	4.78×10^{-1}	2.1
630	146	0.54	0.25	27.6	8.8	100	6.85×10^{-1}	1.5
800	183	0.43	0.23	30.0	9.5	200	1.09	0.91
1000	229	0.34	0.22	31.4	10.0	380	1.66	0.60

* These values are suspect owing to the fact that the method used for measuring reverberation times is inaccurate below 315 Hz.

TABLE 2 AIRBORNE NOISE PREDICTIONS FOR CONFORMAL GEAR NOISE

HARMONIC NO.	FREQUENCY (Hz)	SOURCE* SWL(dB)	PREDICTED SPL(dB)		MEASURED SPL(dB)	
			ABOVE ROOF	CABIN	ABOVE ROOF	CABIN
1 C	446	112.5	114	108.5	116	110
2 C	892	107.5	109	103.5	112	103
3 C	1338	104.5	106	98.5	108	96
4 C	1784	102.0	103.5	92.0	103	94
5 C	2230	100.5	102	91.5	102	89
6 C	2676	99.5	101	90.5	100	86
7 C	3132	98.0	99.5	84.5	96	85
8 C	3568	97.5	99	86	98	84

* Normal operating condition is 530 lb. ft. torque and 6164 rpm.

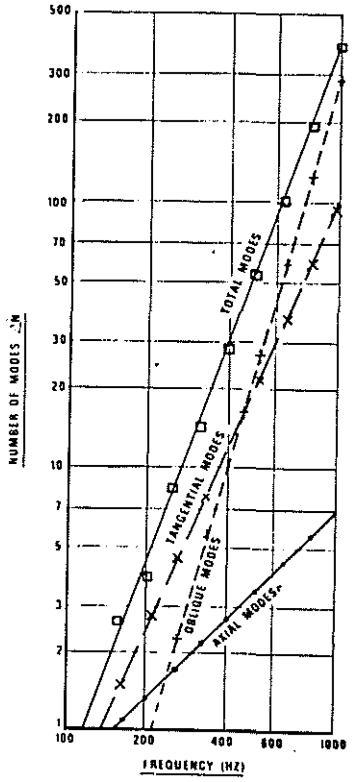

Fig. 1, NO OF MODES ΔN IN A 1/3 OCTAVE BANDWIDTH Δf CENTRED AT FREQUENCY f.

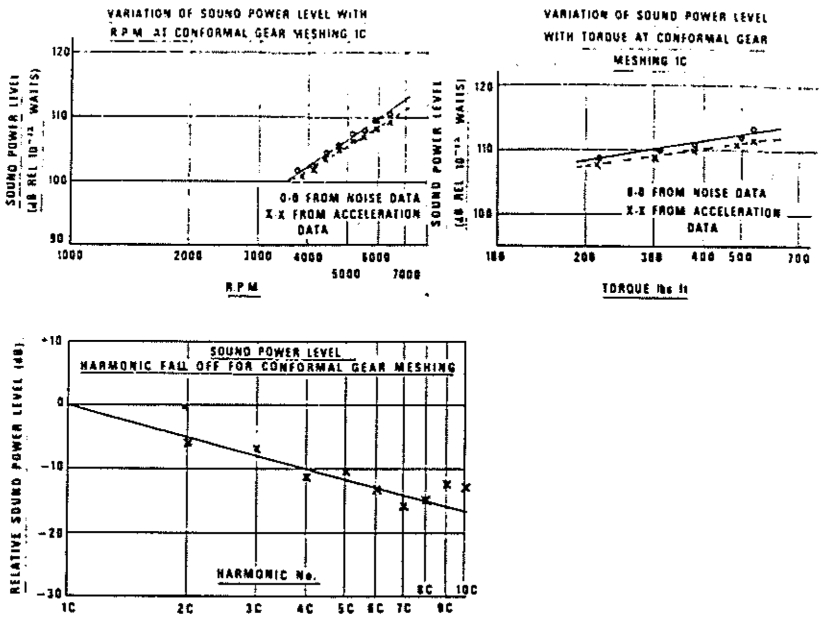

Fig. 3, SOUND POWER LEVEL VARIATIONS WITH TORQUE, R.P.M., & HARMONIC No.

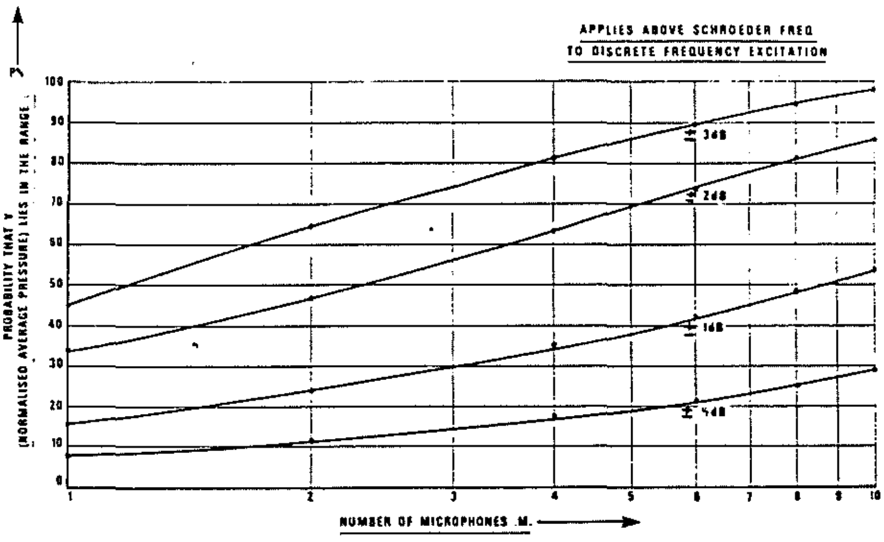

Fig 2 SOUND FIELD PROBABILITY VALUES v. No. OF MICROPHONES

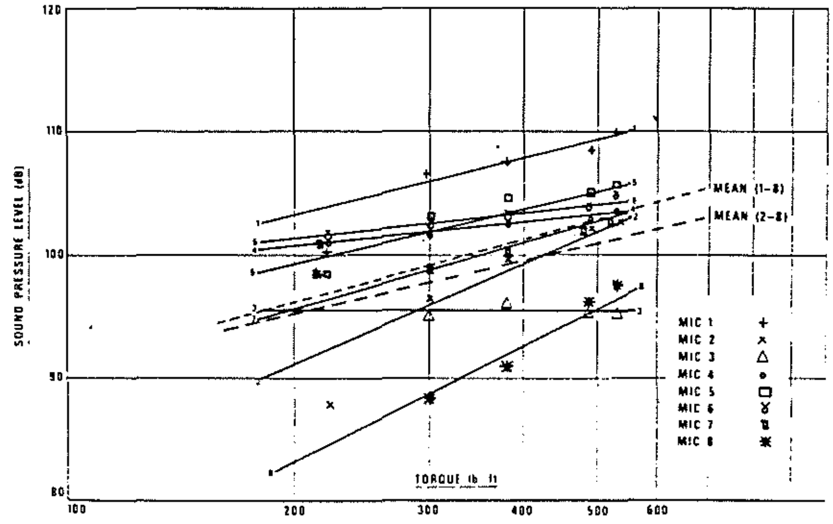

Fig. 4. LYNX CONFORMAL GEAR MESHING FUNDAMENTAL 1C. VARIATION OF NOISE WITH TORQUE FOR EACH MICROPHONE POSITION

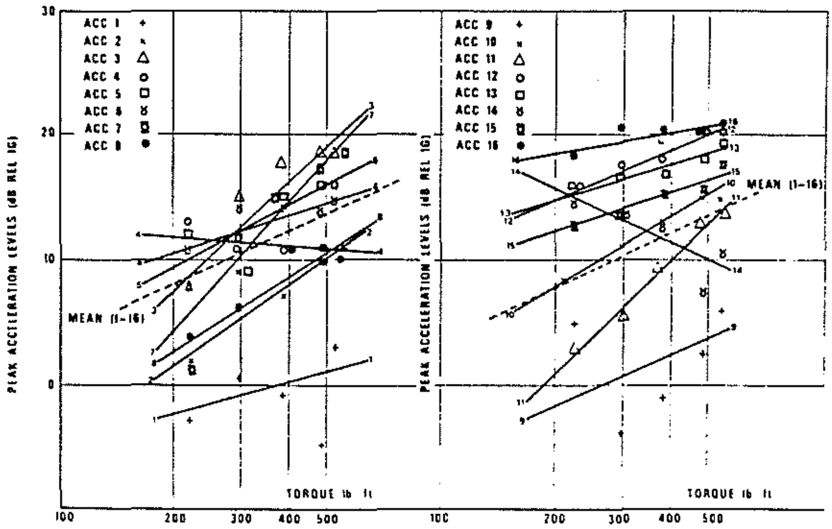

Fig. 5. LYNX CONFORMAL GEAR MESHING FUNDAMENTAL 1C. VARIATION OF ACCELERATION FOR EACH ACCELEROMETER POSITION

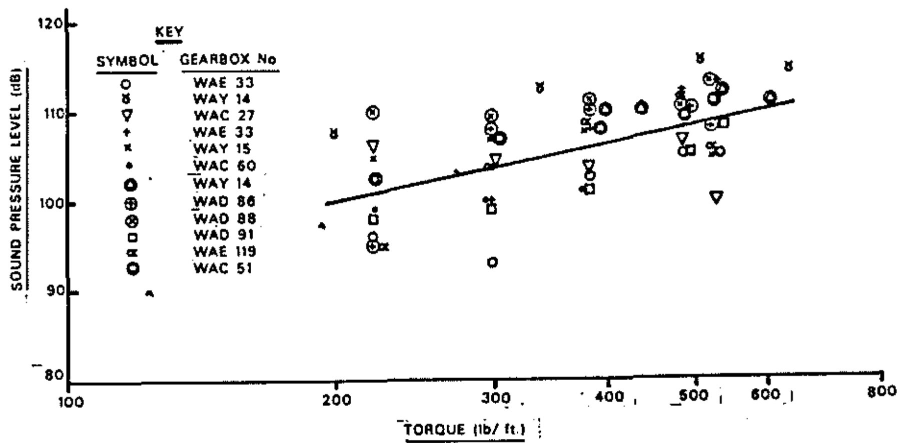

Fig. 6 LYNX CONFORMAL GEAR MESHING FUNDAMENTAL IC VARIATION OF NOISE WITH TORQUE (FROM TEST RIGS)

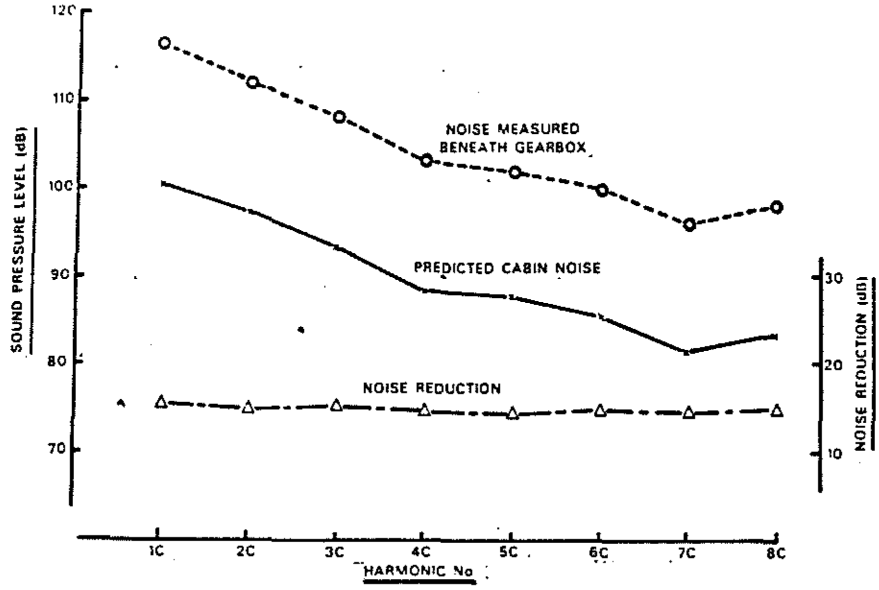

FIG 7. RESULTS OF AIRBORNE NOISE EXCITATION

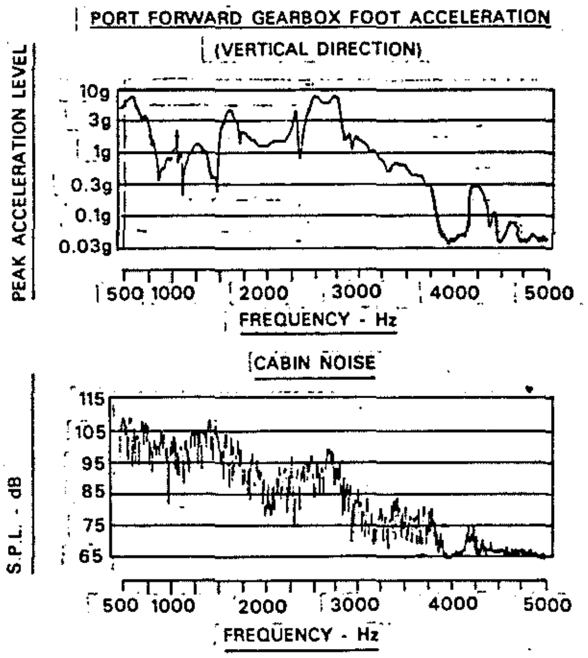

FIG 8. TYPICAL NOISE & ACCELERATION DATA DURING PORT FORWARD FOOT EXCITATION

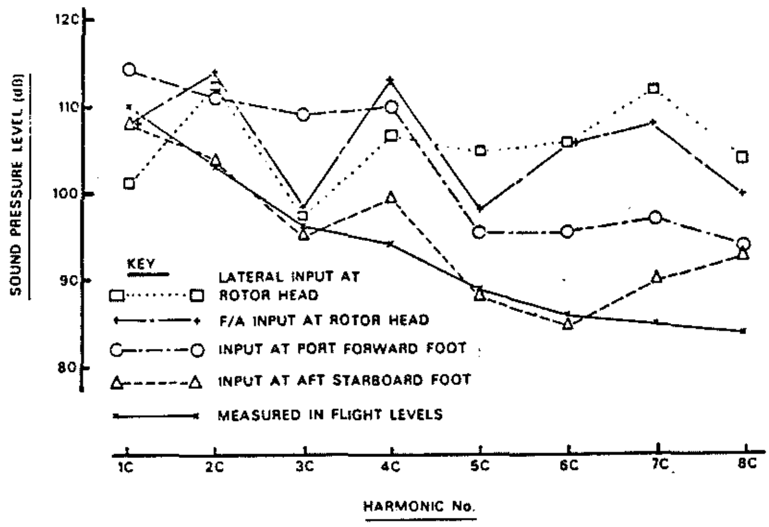

FIG 9. RESULTS OF STRUCTURE BORNE NOISE EXCITATION