THE INFLUENCE OF THE NOISE ENVIRONMENT ON CREW COMMUNICATIONS

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SUMMARY

A general review is presented on the influence of the noise environment on crew communications in helicopters. The signal-to-noise (S/N) ratio at the microphone and the effect of the attenuation provided by the helmet is discussed. This shows that the most important aspect is the S/N ratio at the microphone, particularly when helmets with improved attenuation characteristics are considered. Evidence is presented which shows that in high noise environments, the system S/N ratio is well below that required and hence there is an urgent need to reduce the cabin noise levels and improve the microphone rejection properties.

In this paper the emphasis is placed on environmental/acoustic considerations and no reference is made to the electrical aspects such as distortion effects or signal "clipping"

INTRODUCTION

The noise levels inside many helicopters are sufficiently high to give rise to severe communication problems as well as causing crew fatigue and general annoyance. The noise levels at the ear are essentially a function of the relative levels of the speech at the microphone, the levels of the cockpit/cabin noise and the amount of attenuation provided by the helmet. This results in a poor signal (speech) to noise ratio (S/N ratio) which cannot be improved by the communications system.

Data are presented in this paper to illustrate these aspects and although the values refer specifically to heliccpters, the general trends and implications are equally applicable to the military aircraft (fixed wing) case. Care must be taken, however, in comparing the results, because of the higher speech levels and higher helmet attenuation values, relative to those for the helmet/boom (or throat) microphone combinations used in helicopters, associated with the integral helmet/mask worn by aircraft crew.

SIGNAL-TO-NOISE AT MICROPHONE

The range of noise levels existing in typical helicopter cockpits are indicated in figure 1 together with the corresponding long term rms speech level.

The speech levels quoted are those measured 1 cm from the lips and hence are appropriate to the level experienced by a 'boom microphone' of the type commonly used in helicopters. Also indicated on the figure are the levels appropriate to the Sea King helicopter and a pre-production Lynx helicopter. Fo convenience, the upper limit of the band of noise levels which represents the maximum levels measured in current helicopters - has been termed "noisy" cockpit and the lower boundary as "quiet" cockpit. In practice, of course, a helicopter spectrum is 'peaky' in nature and even if some of the octave band levels are near or on the upper limit shown, other octave band levels could be near the lower limit indicated.

The 'boom' microphone used in helicopters has noise cancellation properties which reject certain regions of the ambient noise relative to the speech. The appropriate corrections for a typical boom microphone have been applied to the helicopter data and the results are shown in figure 2. This shows that the S/N ratio in the important 1 kHz/2 kHz regions is extremely poor on the "noisy" heli copter. The helicopter spectrum, however, contains discrete frequency components and even if the cockpit is relatively quiet, one or two octave bands will be of a high level - this is illustrated for the case of the Lynx and Sea King on figure 1. Thus at one or more octave bands the signal-to-noise ratio on most helicopters is very likely to be near the value shown for the "noisy" cockpit.

Throat microphones are often used in UK helicopters in place of 'boom' microphones. These have better noise-cancelling properties but the speech is generally of inferior quality. Precise figures are not readily available but it has been suggested (ref. 1) that this reduction in voice quality is offset by the improved noise rejection. Thus, it seems reasonable to apply the boom microphone corrections and assume that they are equally applicable to the use of throat microphones; this approach has been adopted in the brief review presented in this paper. Some measurements have been made under operating and laboratory conditions and these suggest that above 1/2 kHz the noise rejection properties are considerably enhanced by use of a throat microphone. This apparent advantage appears, however, to be offset by the lower speech levels and thus, for all practical purposes, the boom and throat microphones can be assumed to give similar results.

HELMET ATTENUATION

The attenuation values for helmets normally quoted by manufacturers and referred to in the general literature are based on results from 'Real Ear at Threshold' (REAT) tests. These tend to give an overoptimistic impression of the noise protection provided by a helmet and from a practical point of view, it is the actual Transmission Loss (TL) results which give a true indication of the attenuation properties of a helmet in a real environment. In the REAT method, the attenuation figures are obtained from the difference of hearing threshold measurements with and without the helmet (refs. 2 and 3), while the TL values are obtained by determining the difference between the noise level at the ear (measured by a microphone inserted inside the ear muff) and the noise external to the helmet. In this latter test it is usual to make the measurements within a real helicopter or in a test chamber in which the helicopter environment is simulated. It is well known that these methods give very different results, although there appears to be a general confusion in the use of the two forms of results. A typical set of results for the SPH-4 helmet, which is manufactured by the Gentex Corporation of Carbondale, Pennsylvania, and used extensively in the U.S.Army, is shown in figure 3. The REAT results are those quoted for the helmet by the U.S. Army[1] and the TL values have been obtained by Westland Helicopters Ltd. (WHL). As can be seen the real attenuation or transmission loss values are considerably lower than those obtained by using the REAT method. The differences at the low frequencies (250 Hz and below) are of the order expected and of particular importance in the case of a helicopter because of the high levels of low frequency noise present in the cockpit/cabin. The difference between the two methods in the low/mid frequency (500 Hz) range are larger than anticipated and those which occur at high frequency (4 kHz) were not expected. It will also be noted that in the mid/high frequency range (2 kHz) the two methods give, for all practical purposes, identical results. It has also been found that slightly different results are obtained with different types of noise sources; this is, however, of secondary importance when compared to the variation from 'test-to-test'.

It is also clear from the results presented in Figure 3, and other results, that if REAT attenuation values are used to evaluate the protection offered to a pilot/crew member by a helmet, then misleading results can be obtained. In the author's experience, it is not possible to calculate the difference between TL and REAT test results and thus a true evaluation can only be made if TL tests are conducted.

It also follows from such analysis that many of the claims made recently about the dramatic increase in protection provided by the new generation of helmets are incorrect since the comparisons have in the main been made between the known TL values for the existing helmets and REAT results for the new helmets. This is illustrated on Figure 3 which shows the TL values for the Mk.3 helmet traditionally used by the UK helicopter pilots/crew members (ref. 1). As can be seen, although the new helmet offers considerable improvement, particularly at the higher frequencies, the gain at the low/mid frequencies are far less than those suggested by incorrectly comparing the REAT results for the SPH-4 and the TL values for the Mk.3 helmet.

A new helmet, the Mk.4, is currently being introduced into service in the UK. This helmet has according to a preliminary evaluation similar or slightly superior attenuation characteristics to the SPH-4. Thus, the observations made in this paper in relation to the SPH-4 helmet, on which a fairly detailed investigation has been conducted, are, in general, equally applicable to the Mk.4 helmet.

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[1] Communication from Department of Army, U.S. Aeromedical Research Laboratory, Fort Rucker, Alabama, Oct. 1974.

INFLUENCE OF HELMET ATTENUATION

The influence of the helmet attenuation on the S/N at the ear (with intercom off) can be assessed from the TL data. Consider firstly the standard Mk.3 helmet which is used by helicopter crews in the UK Forces. This provides attenuation which increases from practically zero at low frequency (125 Hz) to over 30 dB at 4 kHz. These attenuation values have been applied to the data to give the corresponding levels inside the helmet and these are illustrated in figure 4.

It is generally accepted that the long term speech overall rms level should not exceed 105 dB since, at levels above this, intelligibility is decreased. However, if hearing damage is taken into account, a lower level would seem appropriate. This is, however, a complex subject since factors such as exposure duration, frequency, and rest periods must be taken into account. Within the UK the general consensus is that an appropriate acceptable level would be 90 dB (A) This is in line with the general approach being adopted in a number of fields (including the protection of the industrial worker). It is difficult at the present time to finalize the most desirable limit and for this reason both "speech at the ear" criteria have been added to figure 4. Considering firstly the "105 dB limit" then it will be observed that the S/N on a noisy helicopter is relatively poor. If the "90 dB(A) values" are assumed to apply, then even the quiet helicopter gives rise to a problem in the two lower octave bands considered. If helmets with improved attenuation properties are used, then the overall position is improved. Figure 5 shows the results, corresponding to those presented in figure 4, which would be applicable if a SPH-4 helmet was used. There is typically a 7 dB improvement (relative to the Mk.3 helmet) in attenuation over the complete frequency range (including the low frequency end) and thus the effective S/N ratios are considerably increased.

SYSTEM SIGNAL-TO-NOISE RATIO

Speech signals cover a dynamic range of 30/40 dB with the peaks being typically 12 dB above the long term rms value. For speech to be completely intelligible, it is generally accepted that the ratio of the long term rms to long term rms "noise" level at the ear should be at least 20 dB. Thus, the system should be capable of handling peak levels 32 dB above the basic noise level. According to reference 1, sentences used by aircrew can generally be understood from their context, providing the ear is not overloaded; a long term S/N ratio of 9 dB is just considered acceptable. A review within WHL has suggested, however, that with a more flexible vocabulary, a S/N ratio in the order of 15 dB would be more appropriate.

The communications system essentially covers the frequency range from 250 to 3000 Hz and in deriving the figures quoted above, it is assumed that there are no major bandwidth limitations on the speech transfer. If such reductions in bandwidth occur, then an increase in the signal-to-noise ratio is required to maintain intelligibility.

From the results produced in figures 4 and 5, the effective system signal-to-noise ratios can be derived. These have been determined for the Mk.3 and SPH-4 helmets, respectively, and for the "noisy" and "quiet" cockpit configurations considered. The results are shown in figures 6(a) and 6(b) for the Mk.3 helmet/quiet helicopter and Mk.3 helmet/noisy helicopter, respectively. Figure 7 shows the corresponding result for the SPH-4 helmet, but in this case, the "noisy" helicopter results only have been shown since the system signal-to-noise ratio is largely controlled by the microphone cancellation properties. The summation effect of the two individual noise signals arriving via the microphone and through the helmet has been taken into account and the shaded area represents the system S/N ratio. As can be seen, the "noisy cockpit/Mk.3 helmet" results in an unacceptable S/N ratio (figure 6(b)) and even when the improved helmet is used (figure 7) the S/N ratio is poor. It will also be observed that the S/N ratio is not uniform across the communication band (250 Hz - 3000 Hz). In addition, the helicopter spectrum largely consists of discrete frequencies and thus masking effects and possible distortion in the system has to be taken into account. It is clear, however, from these results that although the improved helmet is required, the ambient (cabin noise) levels must be lowered and/or the microphone cancellation properties improved.

DAMAGE RISK CRITERIA

In the preceding discussion, the problem relating to Damage Risk has been ignored and the assessment was simply based on the signal-to-noise ratio at the microphone and the "speech" level requirement at the ear. The data concerning hearing damage are confusing and often contradictory. It is, however, generally accepted that for an 8 hour/day - 5 days/week exposure, an upper limit of 90 dB(A) is acceptable. The situation in the case of rating helicopter noise is further complicated by the fact that the Damage Risk Criteria commonly quoted refer essentially only to broadband noise. The audio spectrum on a helicopter is, however, dominated by a series of discrete frequencies arising from the gearbox. It is generally accepted that an allowance for such tones can be made by reducing the allowable levels by 5 dB(A). There is also a general feeling that the suggested criteria should be applied to aircrew even though they are not exposed for the full 40 hours per week. Thus, it seems reasonable to assume that the 85 dB(A) criteria should be applied in the helicopter case. This limit (in terms of octave band levels) has been superimposed on the levels "at the ear" for the Mk.3 helmet and SPH-4 helmet, respectively, as shown in figures 8 and 9. For reference, the octave band levels corresponding to an upper limit of 90 dB(A) are also shown. As can be seen the noisy helicopter exceeds the recommended values in several octave bands when the Mk.3 helmet is used and even the quiet helicopter levels are very close to the 85 dB(A) criteria values in the 125 and 250 Hz octave bands. Use of the SPH-4 helmet would improve the situation as illustrated in figure 9 and in this case the noisy helicopter values are below the 90 dB(A) limit. Thus, the use of the SPH-4 helmet (or equivalent) would seem essential.

HELICOPTER TESTS

By using a modified Mk.3 helmet, which has a miniature Knowles microphone mounted in the earpiece to measure the level inside and a microphone attached to measure the ambient noise outside the helmet, a series of measurements have been made on a range of pre-production and "in-service" aircraft. In addition to the noise measurements, the electrical signal on the "tel lines" to the earpiece were measured. These tests have given results which confirm the general trends outlined previously and highlighted a number of points.

In one case the levels at the ear inside the helmet were of the same order as the ambient levels outside the helmet. The results obtained are illustrated in figure 10 which show that in the 1 kHz and 2 kHz bands, the levels are to a first order identical inside and outside the helmet. The aircrew concerned were questioned, but could not give any satisfactory explanation why the amplifier volume control was set so high. Thus, there is no real explanation for these results and so it would appear that they resulted from the crew attempting to raise their speech above the level of the noise in the communication system and/or the annoying high level in the low frequency (125/250 Hz) octave bands. This resulted in high levels inside the helmet without, of course, any real improvement in speech quality.

In an attempt to clarify the position relating to these results, a repeat test was planned but unfortunately, this has to be carried out on a different helicopter. The same intercom system was, however, used and in these tests the system volume control was adjusted to the minimum considered acceptable by the crew. This resulted in the levels measured inside the helmet being considerably lower, as illustrated in figure 11 and although no specific subjective tests were performed, the crew tended to agree that the overall communication was equally as good - or rather equally as bad - as on the previous tests. These observations were also confirmed by a subjective evaluation of the recording taken with "speech".

The increase in noise in the 125 Hz octave band is, incidently, not dependent on the intercom system and appears to be due to a resonance within the Mk.3 helmet. Thus, the published attenuation value at 125 Hz for the Mk.3 helme used in deriving the levels inside the helmet shown on figure 3 would appear to be in error and rather than an attenuation of 1 dB, there appears to be a 5 dB amplification.

It will also be observed on figures 10 and 11 that the rms speech levels are only a few dB above the "noise" on the intercom system and only in the 250 Hz and 1 kHz levels can a clear difference be seen. The corresponding "tel line" recordings are illustrated in figure 12 and as can be seen the S/N ratio in the 500 Hz to 2 kHz band is only 6/8 dB and hence inadequate for good communications.

REVIEW OF TEST RESULTS

One-third octave band analysis has been performed on a number of conditions recorded in the Lynx. Particular interest was placed on the 'high level' recording and a typical one-third octave band spectrum is shown in figure 13. This shows the levels with the intercom disconnected (noise via helmet), levels when the intercom is switched on and the levels which occur during speech. The speech levels shown are the results of conventional rms "slow" analysis and thus neither represent, the true "peak" or the long term rms value. A brief review, however, suggests that the corresponding long term rms values are in the order of 6 dB below the maximum levels shown - this should be taken into account when comparing the results with the idealized values discussed previously. The results in figure 13 show clearly the impact of the combination of the high cockpit levels and the poor throat microphone cancellation properties. It will be noted that the largest S/N ratio occurs in the 250/800 Hz region. If a lower system gain (amplification) is used, then the complete spectrum (i.e. speech and noise) will be lowered. In the region above 800 Hz. the S/N ratio is largely a function of the microphone properties and the speech-noise S/N ratio in the ear piece will remain for all practical purposes unaltered. Between 200 Hz and 800 Hz, the level at the ear is a function of the noise transmitted through the helmet and hence, as the gain of the system is decreased, the effective S/N ratio at the ear will also decrease. Thus, the overall system S/N ratio will decrease and the intelligibility degraded. It follows from this that a subjective assessment of the acoustic acceptability or otherwise, which is often used in rating the cockpit-cabin noise environments, can be very misleading since the apparent absolute level at the ear is simply a function of the gain setting of the communication system. It is also apparent by a comparison of the 1/1 octave band data in figure 10 and the one-third octave band data in figure 13 - that a detailed evaluation cannot be readily made from the conventional octave band analysis.

In addition to the above, the intelligibility is further influenced by the masking effect of the tones, and the nonuniform earpiece cavity response. Masking effects are difficult to quantify, particularly in the case of helicopters where the levels are varying with time by 10 dB and, in some cases, 15 dB. Currently, octave bands are used for assessing cabin noise levels but limited evidence suggests that even if allowances are made according to available methods for discrete frequencies, these methods of rating the noise underestimate the annoyance and influence on intelligibility. In a simple test conducted using Lynx data, it was found that when the noise levels in the 1 kHz and 2 kHz octave bands were decreased by 10 dB from the levels indicated in figure 10 it had no effect on the apprent clarity of speech or the subjective impression. Preliminary evaluation suggested that the signal-to-noise ratio in the individual bands, or in other words the discrete frequency-to-broadband levels, had a marked effect on the subjective impression and can influence the intelligibility. It is also apparent that the nonlinear response of the ear cavity - measurements made by WHL suggest variations (dips and peaks) of $\pm$ 10 dB - the spectrum is far from 'flat' as illustrated in figure 14.

CONCLUDING REMARKS

The S/N ratio at the ear is controlled by the cancellation properties of the microphone and the helmet attenuation. When improved helmets are used, the system S/N ratio will become more dependent on the microphone rejection properties in most of the helicopters and will remove the problems associated with hearing damage arising from high levels at the ear.

It follows that either the noise levels in the cockpit have to be lowered or alternatively the noise attenuation properties of the microphone improved. In this context it is of interest to note that the noise rejection characteristics of the boom microphone - and, by implication of the WHL tests, the effective rejection of the throat microphone - decrease with frequency and approach zero at 4 kHz. The mask/mask microphone provides, on the other hand, an effective "shield" whose rejection increases at 1 kHz and above. Unfortunately, at 1 kHz the value is only 5 dB but some general communication noise exclusion microphones provide even better noise rejection with the values reaching typical 20 dB at 1 kHz. Thus, it would seem desirable to attempt to incorporate the advantages of both systems to provide a wide frequency range rejection. Alternatively, concepts of placing the microphone inside the helmet would seem well worth while, particularly when helmets with improved high attenuation at low frequencies are developed. Reduction of the noise at the source must, of course, be pursued with equal vigour but there is a limit, particularly in the cockpit area. Treatments can be readily applied to the cabin area and although these in turn produce some reduction in the cockpit area, it is unlikely that significant gains can be made before radical new fuselage design concepts currentl being considered can be employed.

With the improved helmets, it is worth considering placing more emphasis on the microphone rejection of the noise, since, if this could be achieved, then higher ambient noise levels could be tolerated without infringing Damage Risk Criteria. This solution could be applied to all forms of aircraft/helicopters, whilst noise reduction techniques will, in general, have to be related to specific designs. The overall cost of developing an acceptable microphone system in the long term would, therefore, be most likely to be less than the cost of individual noise control schemes. Even so, it does appear that attempts at obtaining improvements in both aspects must be considered if the communications problems are to be overcome.

REFERENCES

1. On the Specification of Maximum Noise Levels in Aircraft. RAE Technical Report 72089, June 1972.

2. Method for the Measurement of the Real Ear Attenuation of Ear Protectors at Threshold. S3.19, American National Standards Institute, 1974.

3. Method of Measurement of the Attenuation of Hearing Protectors at Threshold. BS5108, British Standards Institute, London, 1974.

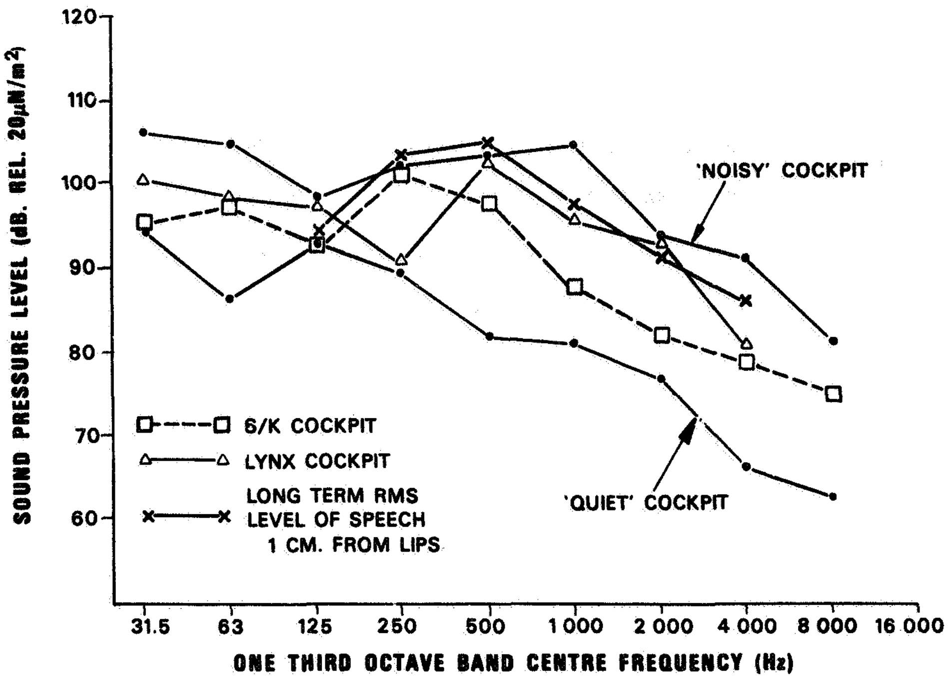

Figure 1.- Helicopter internal noise levels compared with speech levels.

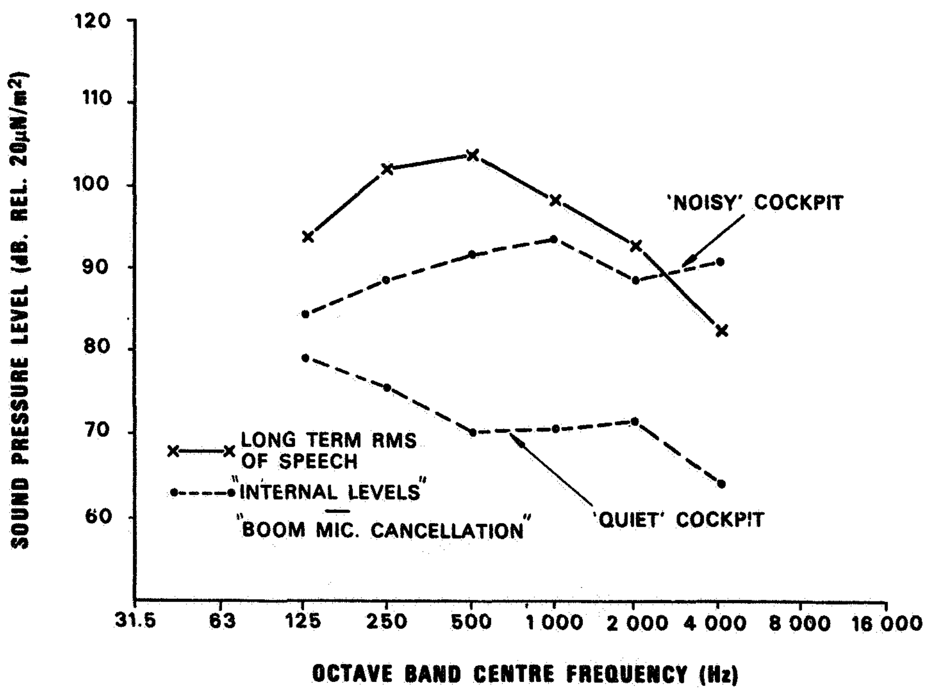

Figure 2.- Ear piece noise levels (boom microphone cancellation corrected) compared with speech levels.

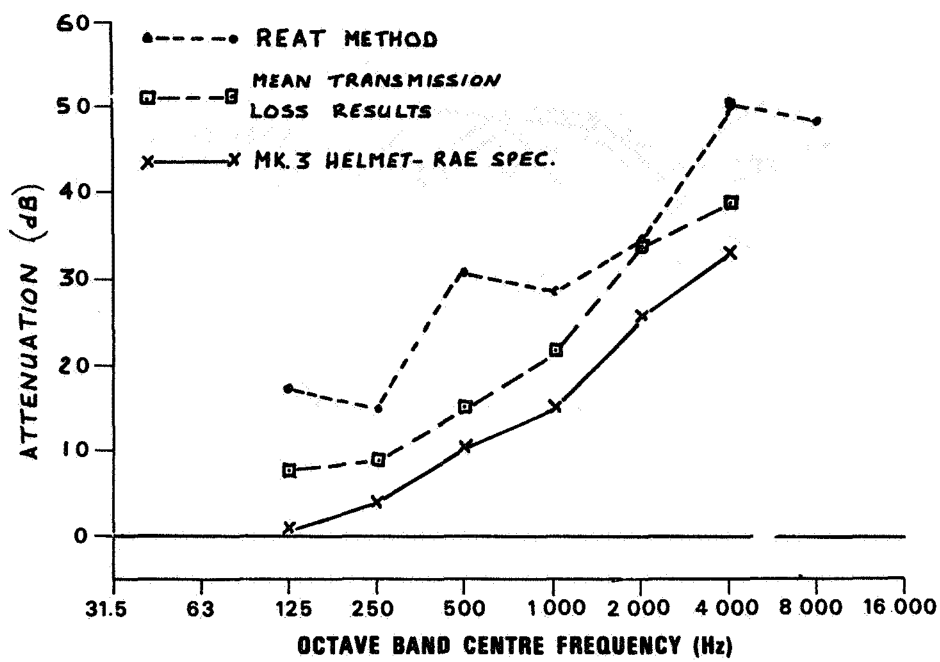

Figure 3.- Attenuation of Mk.3 and SPH-4 helmets.

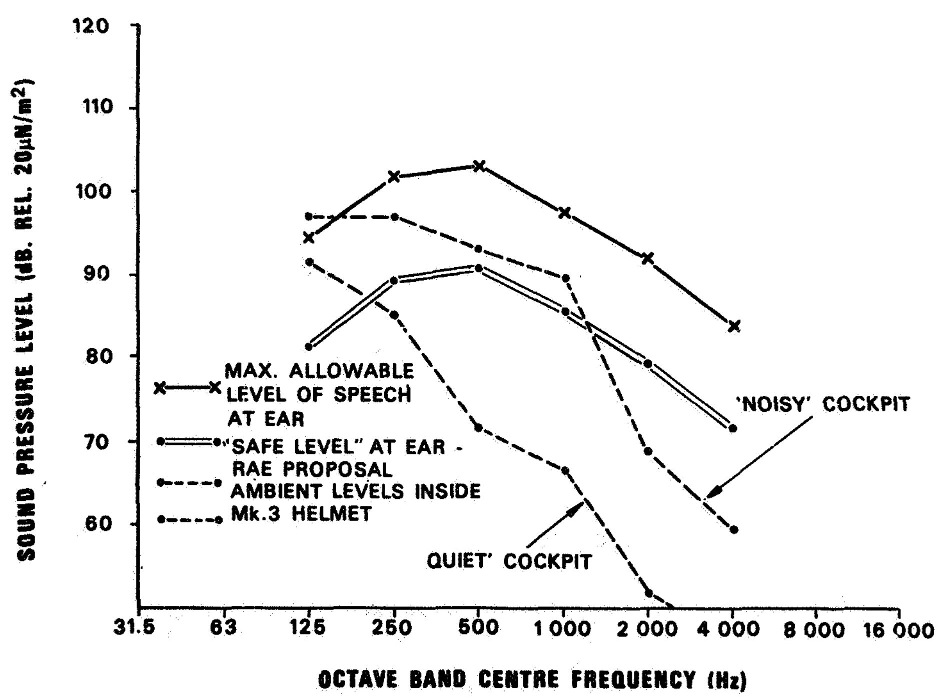

Figure 4.- Noise levels at ear - Mk.3 helmet.

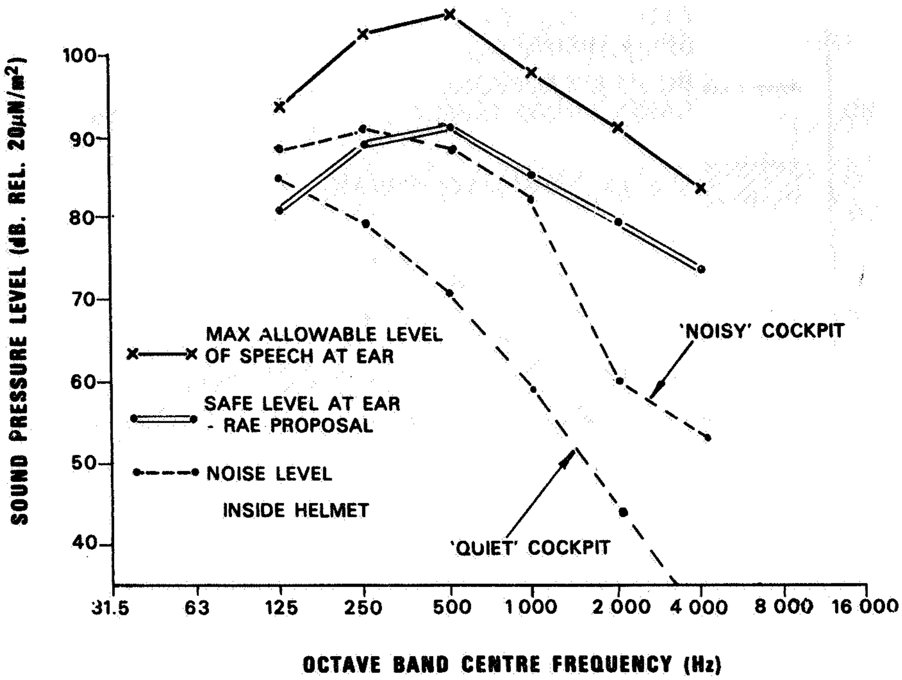

Figure 5.- Noise levels at ear - SPH-4 helmet.

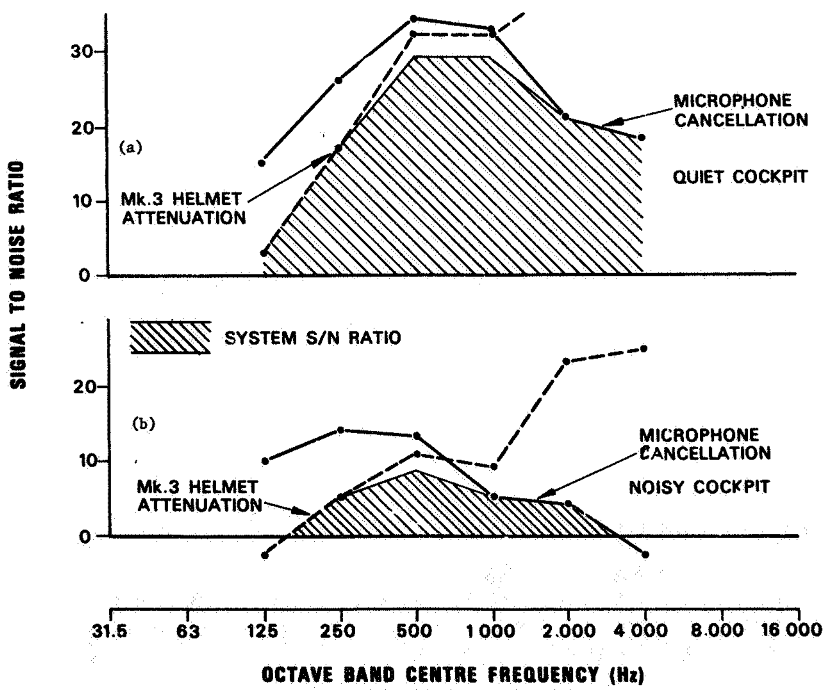

Figure 6.- Signal to noise ratios based on a speech level of 105 dB - Mk.3 helmet "quiet" and "noisy" cockpits.

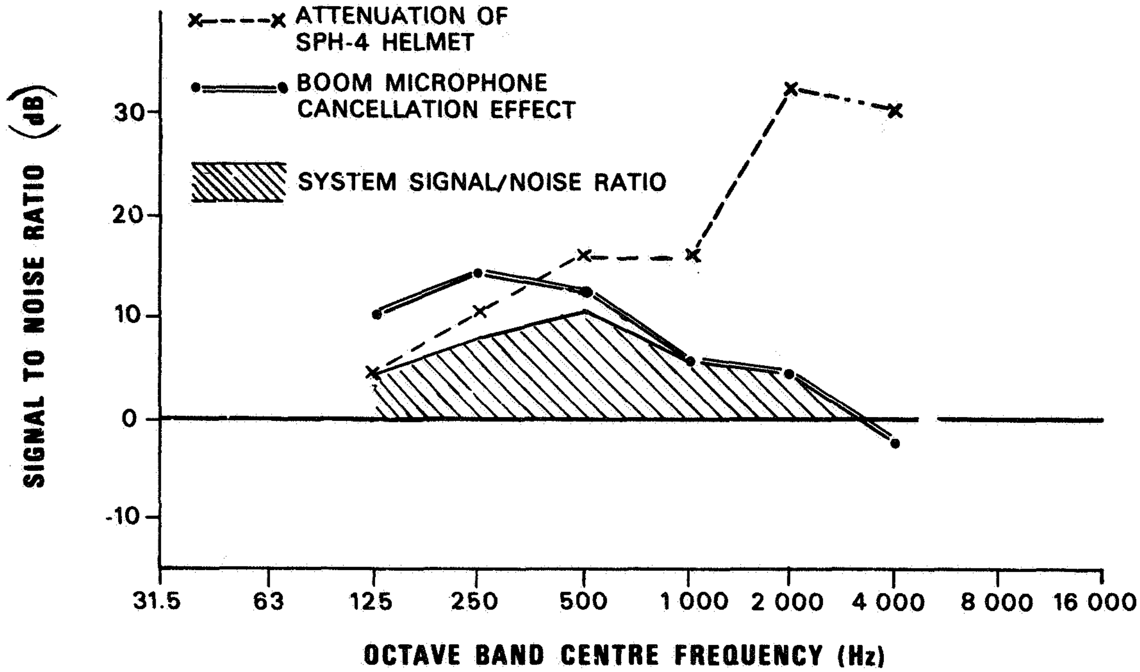

Figure 7.- Signal to noise ratios based on a speech level of 105 dB - SPH-4 helmet "noisy" cockpit.

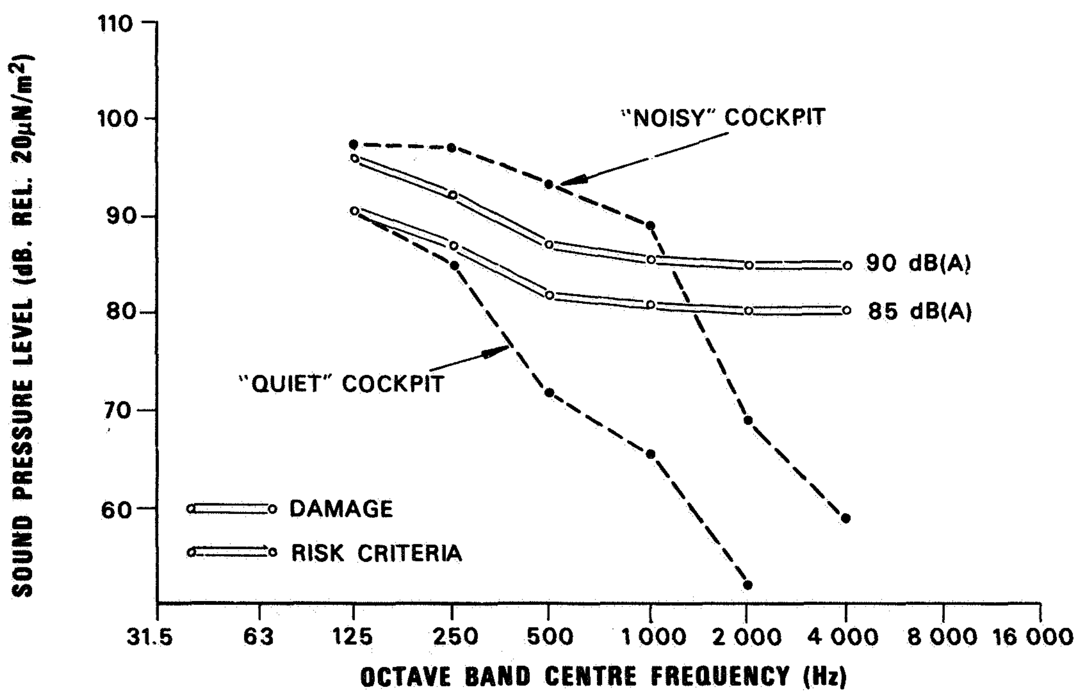

Figure 8.- Levels at ear compared with damage risk criteria - Mk.3 helmet.

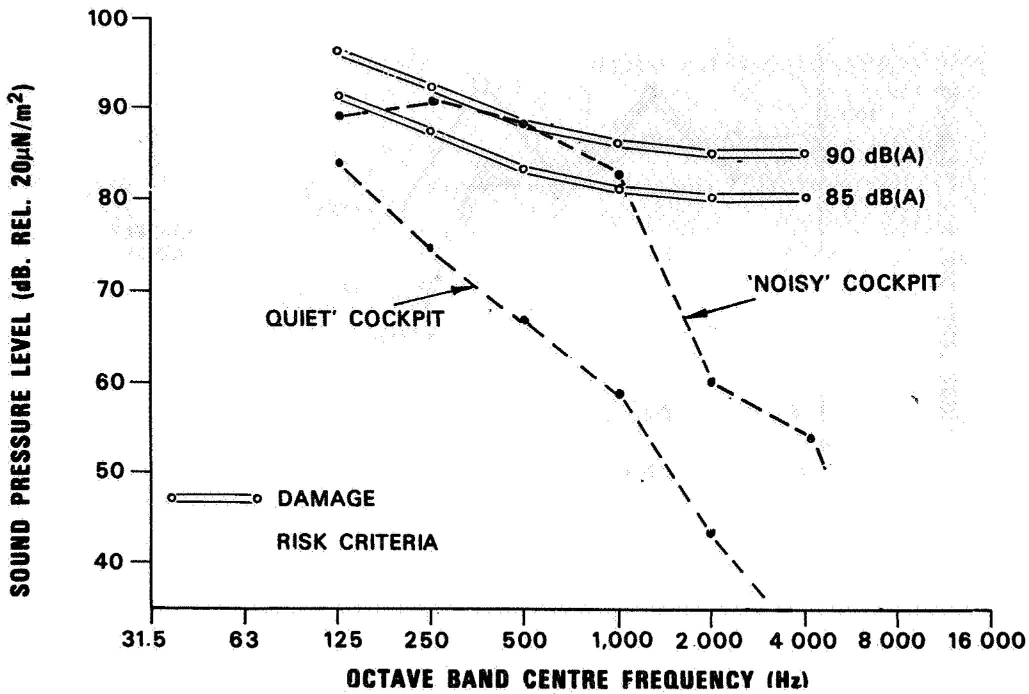

Figure 9.- Levels at ear compared with damage risk criteria - SPH-4 helmet.

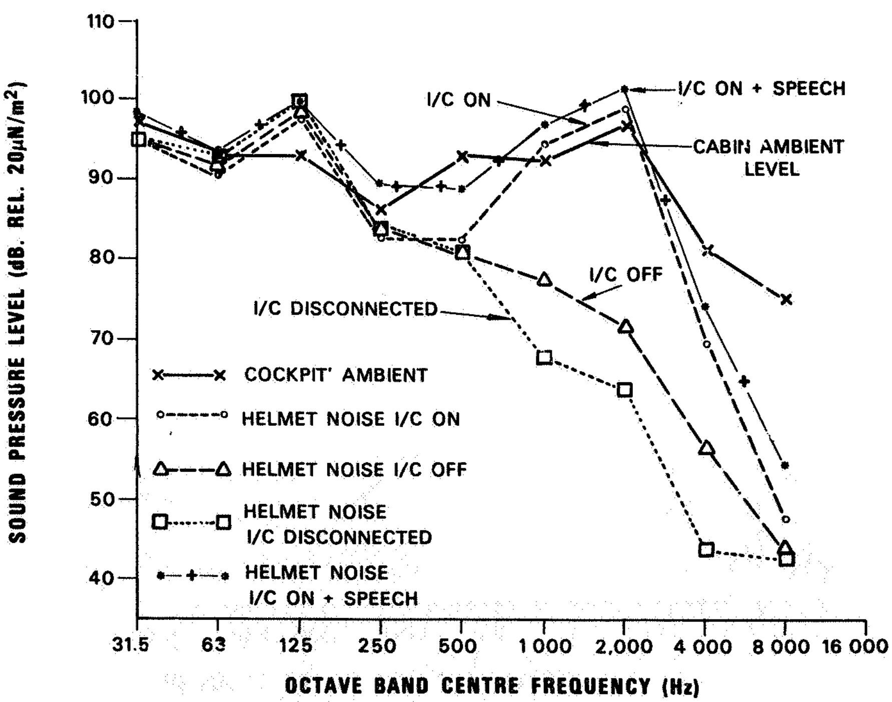

Figure 10.- Lynx intercom noise - levels at ear - Mk.3 helmet.

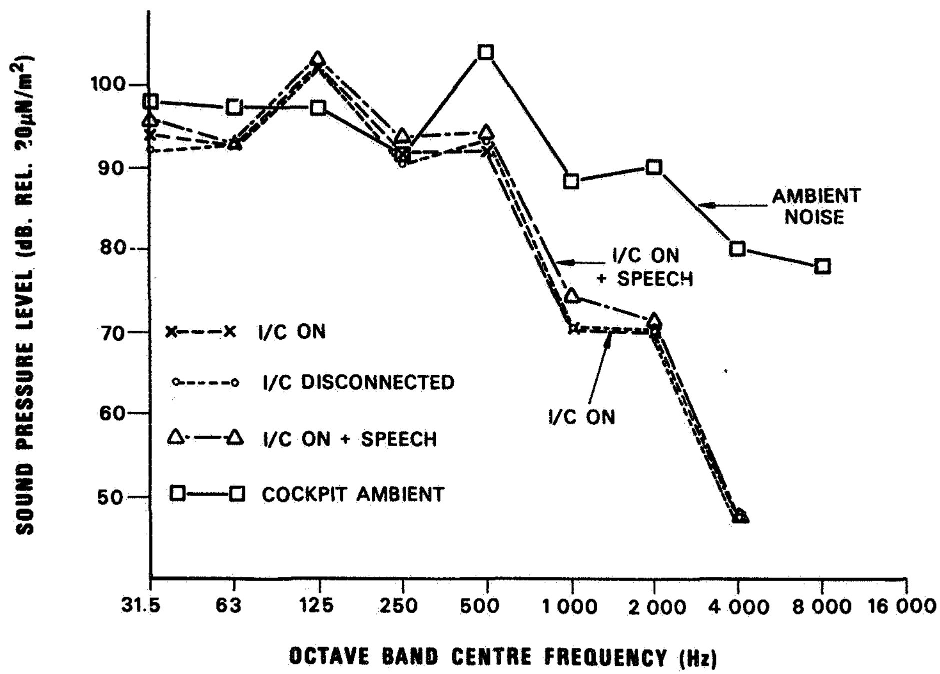

Figure 11.- Lynx intercom noise - levels at ear - effect of reducing intercom system gain setting - Mk.3 helmet.

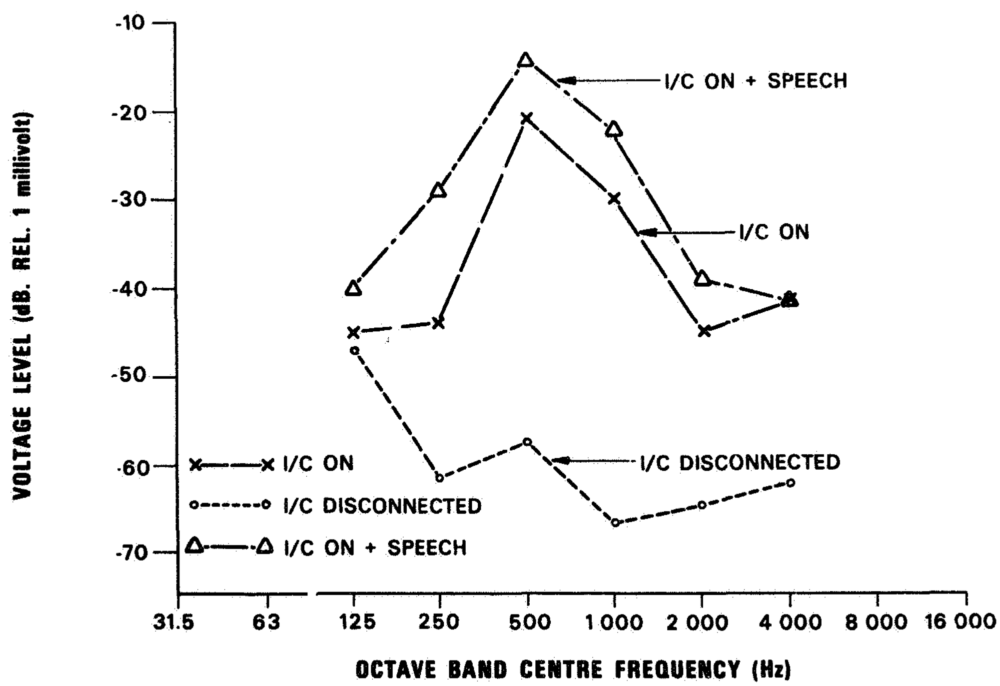

Figure 12.- Lynx intercom noise - electrical signal on headset input.

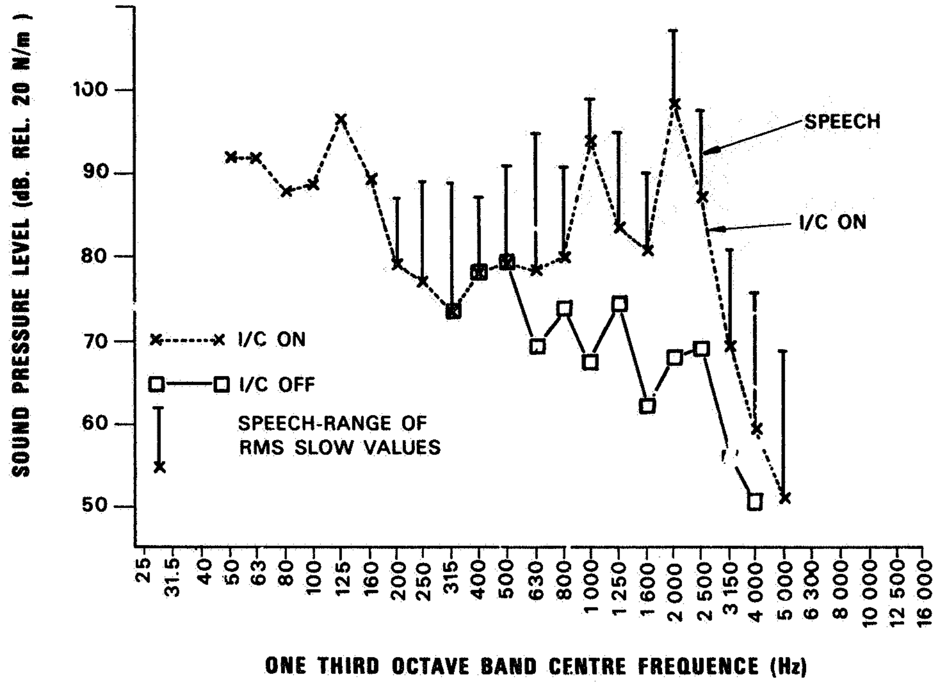

Figure 13.- Lynx intercom noise - comparison of speech and background noise levels.

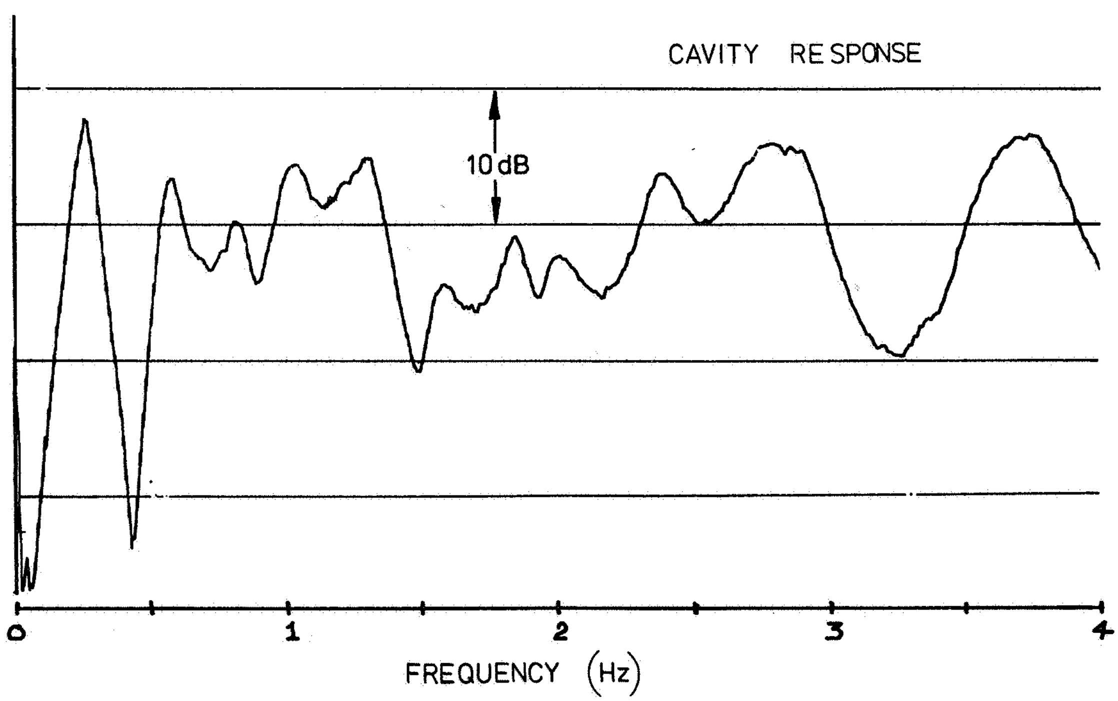

Figure 14.- Frequency response of Mk.3 helmet earpiece.