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METHOD FOR ASSESSING A-WEIGHTED AUDITORY RISK LIMITS FOR PROTECTED EARS

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FOREWORD

The work contained in this report was conducted in the Noise and Hearing Conservation Function of the Otolaryngology Branch under task No. 775508 between May and October 1970. The paper was submitted for publication on 23 October 1970.

This report has been reviewed and is approved.

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ABSTRACT

Recent noise exposure studies employ A-weighted measures as the basis for estimating varying degrees of potential auditory risk. Since most auditory risk criteria are based on unprotected exposures, aerospace applications require adapting the criteria to attenuated conditions. This report provides specific guidance for evaluating conditions of noise exposure when personal ear protection is worn (headsets or earplugs).

Generalized spectra are presented for noise measured within cockpits of 249 aircraft divided into eleven groups, each representing a different airframe-to-powerplant mating. A-weighted levels for attenuated and nonattenuated noise are shown for each of the eleven groups of aircraft included in this study. Relationships between C- and A-weighted values for different spectra (octave bands) are described, and the use of C-A as a correction factor is evaluated. Generally, small values of C-A yield greater amounts of attenuation (A-weighted, attenuated) than larger values of C-A. The results of this study can be used to predict differing degrees of A-weighted attenuation provided by either headsets or earplugs when C-A is known.

METHOD FOR ASSESSING A-WEIGHTED AUDITORY RISK LIMITS FOR PROTECTED EARS

I. INTRODUCTION

A history of the evolution of auditory risk criteria can be found in a report contained in the 1966 Proceedings of the Bioenvironmental Engineering Symposium (4). A discussion of more recent criteria is contained in a report recently completed by the authors (6) and in another in preparation (5). The authors believe that the set of criteria proposed by Working Group 46 of the National Research Council, Committee on Hearing, Bioacoustics, and Biomechanics (12) provides guidance adequate for identifying and designating potentially hazardous exposures (unprotected) to steady-state broad-band and narrow-band noise for which octave-band measurements are available (octaves 250 through 8000 Hz, by center frequency). The auditory risk limits proposed by Working Group 46, however, are somewhat difficult to interpret. This difficulty has been significantly reduced by the use of a simple dial-type calculator (6).

Recently, several investigators have proposed the use of A-weighted levels as an indicator of varying degrees of auditory risk (1, 2, 7, 9-11). The A-weighting, as a measure of auditory risk, has been adopted by the U.S. Department of Labor (8), the American Conference of Governmental Industrial Hygienists (9), the American National Standards Association (7), the American Industrial Hygiene Association (11), and others (2, 3, 8, 11).

The A-weighted level may eventually replace other currently accepted criteria which employ octave-band measurements. However, the success of such a change will depend on correlating A-weighted levels with the criteria that utilize octave-band data.

Botsford (1) has attempted to define auditory risk limits which are compatible with A-weighted measures. He has proposed methods by which A-weighted levels can be assessed in a manner similar to octave-band data for risk limits proposed by Working Group 46 (2). Speaking at a special symposium dealing with transportation noises, he mentioned some of the problems:

> "One deterrent to the acceptance of A-weighted sound levels as an index of noise hazard was that noise exposure limits had been expressed in terms of octave-band sound pressure levels and no satisfactory method for converting these limits to A-weighted sound levels had been developed (p. 105, ref. 2).

Botsford further stated:

> "It was clear from the outset that noises having similar spectra could be ordered in intensity, hence hazard, using A-weighted sound levels because, with the spectrum fixed, intensity was the only remaining aspect of the noise needing quantification, which the A-scale does adequately. Thus, making noise spectrum a consideration in developing the relations sought should increase accuracy markedly. Information on the type of noise spectrum is provided by the difference between the C- and A-weighted sound levels in a noise, (this difference to be) designated C-A. A small value of C-A indicates a concentration of noise energy in the frequency range above 1000 Hz where the A-weighted response falls progressively below the C-weighted response as the noise frequency becomes lower. Thus, the value of C-A indicates the type of noise spectrum and was selected as the spectral parameter to be used in developing the relations sought." (p. 105-106, ref. 2)

It is this weighting factor--the difference between C and A--that prompted the authors to investigate acoustic spectra found within aircraft cockpits and to attempt to clarify the use of this spectral parameter for conditions of protected as well as unprotected exposures.

II. APPROACH

The acoustic noise measured in the cockpits of 249 fixed- and rotary-wing aircraft during conditions of normal cruise has been converted from octave band to equivalent A-weighted levels. Table I shows the correction factors (dB) employed in converting octave-band data to equivalent A-weighted sound levels relative to C-weighting (13). Although slight differences exist between old and new preferred octave-band weighting values, both were used to obtain data for the 249 aircraft included in this study.

TABLE I

Correction factors for computing A-weighted levels from octave-band data

Old octaves (in Hz)	dB correction	New octaves (in Hz)	dB correction
53	-27	63	-24
106	-17	125	-15
212	-10	250	-8
425	-4	500	-3
850	0	1000	0
1700	+1	2000	+1
3400	+2	4000	+2
6800	+2	8000	+2

To evaluate the attenuating effects of ear protection devices on A-weighted sound level measurements, two types of devices were chosen. Figure 1 shows the noise attenuation values obtained for headsets (H-154 fitted in the Air Force APH-5 crash helmet) and earplugs (V-51R) (6).

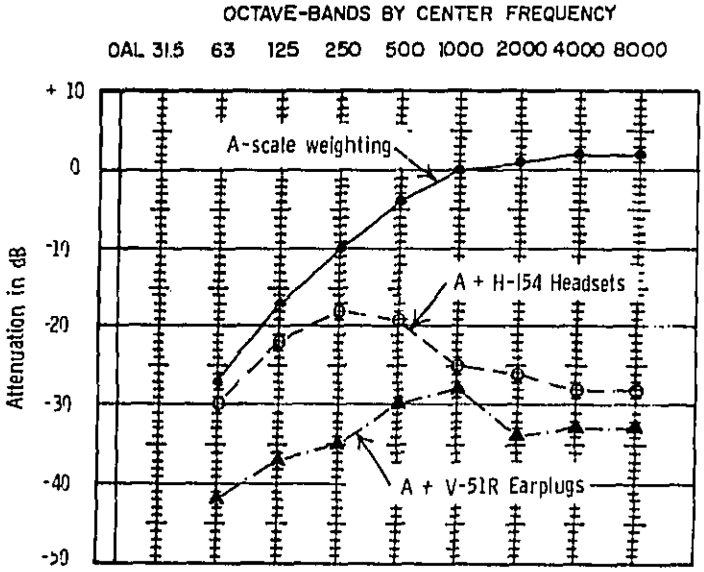

FIGURE 1

Comparison of nonattenuated A-weighting levels and modified A-weighting levels resulting from attenuation provided by standard Air Force headsets (H-154) and earplugs (V-51R).

This procedure is essentially the same as proposed by Glorig (7). As shown, the amount of attenuation expected for each octave is added to the frequency weighting which the A sound level circuit provides. For example, the mean attenuation provided by H-154 headsets is 3 dB at the lowest octave (63 Hz) and the frequency weighting required for A sound levels in this octave range is 27 dB (old centerfrequency, 53 Hz). Determination of attenuated A-weighted values is achieved by adding these two numerical values--the A-weighting of 27 dB and the attenuation of 3 dB--for a total of 30 dB, the attenuated A-weighting for the lowest octave-band.

The fact that minimal attenuation occurs in the low frequencies is most evident when headsets are considered. As is evidenced in figure 1, an almost inverse relationship exists in the amounts of attenuation provided at frequencies below and above 1000 Hz. This is because the most weighted frequencies in the A-weighted network--i.e., below 1000 Hz--are in the frequency range in which ear protection is least effective (6). As will be shown, noise spectra containing intense elements within the lower frequencies may dominate the A-weighted determinations when attenuated conditions are considered.

III. RESULTS

Figures 2 and 3 illustrate mean spectra for noise measured within the 249 aircraft sampled in this study. Eleven groups of aircraft are represented; 7 in the fixed-wing category (fig. 2) and 4 in the rotary-wing group (fig. 3). Of the 191 aircraft constituting the 7 groups of fixed-wing aircraft, 22 aircraft are powered by one reciprocating engine (1R), 40 aircraft are powered by two reciprocating engines (2R), 19 vehicles are powered by four reciprocating engines (4R), 13 aircraft are mated to two turboprop powerplants (2 TP), 21 aircraft are powered by four turboprop engines (4 TP), 51 aircraft are powered by internally mounted jet engines (J-Int), and 25 aircraft are powered by externally mounted turbojet and turbofan engines (J-Ext).

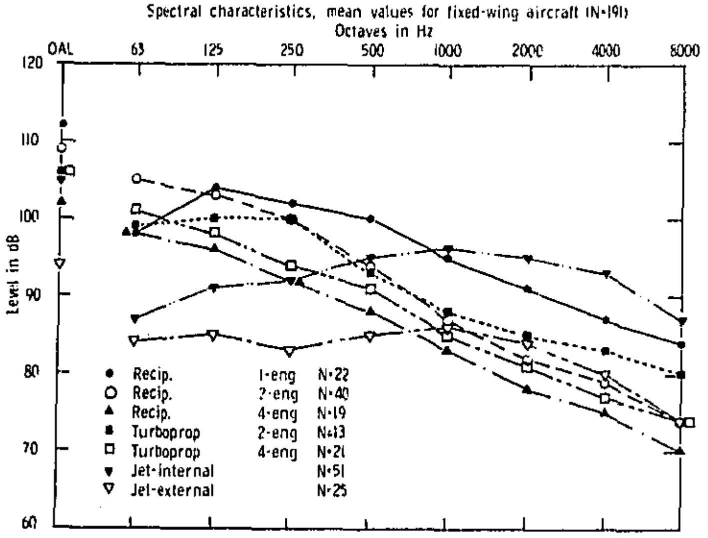

FIGURE 2

Mean noise spectra for seven groups of fixed-wing aircraft during normal cruise.

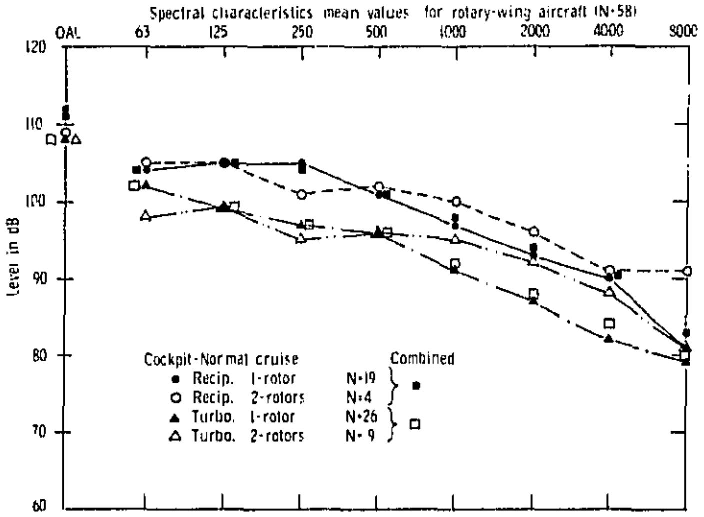

FIGURE 3

Mean noise spectra for four groups of
rotary-wing aircraft during normal cruise.

The spectra shown for these seven groups of fixed-wing aircraft demonstrate the following characteristics:

Aircraft group	Spectral character
IR	A drop of 3.3 dB/octave above 125 Hz.
2R	A drop of 4.4 dB/octave above 63 Hz.
4R	A drop of 4.0 dB/octave above 63 Hz.
2 TP	A drop of 4.0 dB/octave above 250 Hz.
4 TP	A drop of 3.9 dB/octave above 63 Hz.
J-Int	A rise of 2.2 dB/octave to 1000 Hz and then a drop of 3 dB/octave above 1000 Hz.
J-Ext	A relatively flat spectrum through 1000 Hz and then a drop of 4 dB/octave above 1000 Hz.

For the four groups of rotary-wing aircraft (those fitted with 1 or 2 rotors and powered by reciprocating engines, of which a total of 23 were included in the sample; and those fitted with 1 or 2 rotors and powered by turboshaft engines, with a total of 35 included in the sample), the combined spectra shown for each of the two basic groups in figure 3 demonstrate the following characteristics:

Aircraft group	Spectral character
Reciprocating	Relatively flat through 250 Hz, a drop of 3 dB/octave through 2000 Hz, then a drop of about 5.5 dB/octave above 2000 Hz.
Turboshaft	Drop of about 2 dB/octave through 500 Hz; then a drop of 4 dB/octave above 500 Hz.

Comparison of the mean spectra reported in figures 2 and 3 vividly illustrates differences in the noise measured within the aircraft groups included in this study. It can be seen that aircraft, fixed- or rotary-wing, which employ propellers or rotors (for helicopters), tend to have the most prominent noise levels in the lower frequency ranges, with decreases in magnitude as frequency increases. In contrast, fixed-wing aircraft powered by either turbojet or turbofan engines (fig. 2) contain acoustic noise that is more evenly distributed. The effect of spectrum shape on both nonattenuated and attenuated A-sound levels is evidenced in table II.

Values on line 3 of table II were derived by computing C-weighted levels for each spectrum displayed in figures 2 and 3. The computations were done according to instructions given by Peterson and Gross (13). This procedure is essentially a means to add the energy listed for octave bands so that the resultant single number is the C-weighted value to be expected if a sound-level meter were used to measure the overall level of the spectrum being examined. For example, the average spectrum displayed for aircraft with one reciprocating engine (1R) in figure 2 would result in 107.5 dB sound pressure level if measured with a sound-level meter with C-weighting.

Line 4, table II, was derived in the same manner as line 3, but the octave-band levels were adjusted by the values in table I before the computations were made. Each number is the A-weighted level to be expected if the spectrum displayed were measured with an A-weighted sound-level meter.

Values on lines 6 and 7 (table II) were computed in the same way as lines 3 and 4. However, the octave-band levels from figures 2 and 3 were adjusted by the amounts from the two lower curves in figure 1. Therefore, the numbers on lines 6 and 7 represent "at-the-ear" A-weighted values for each type of aircraft when the H-154 helmet or the V-51R earplug are used. Lines 8 and 9 are the differences between lines 4 and 6, and between lines 4 and 7. This represents the reduction in A-weighted level "at-the-ear."

TABLE II

Application of C-weighted and attenuated and nonattenuated A-weighted values to noise data by types of aircraft

Types of aircraft	(Line)	1R	2R	4R	2TP	4TP	J-Int	J-Ext	RW Recip	RW Turbo
Number in sample	2	22	40	19	13	21	51	25	23	35
Computed C-weighted level	3	107.5	108	101	105	103.5	101	93	110	105
Computed A-weighted level	4	101.5	97	90	96.5	91	101.5	90.5	103	97.5
Difference (C-A)	5	6	11	11	8.5	12.5	0.5	2.5	7	7.5
Computed attenuated A-weighted level										
H-154 headsets	6	89	87.5	79.5	86	82	80	71	90.5	84.5
V-51R earplugs	7	74	71	64	70	66	71	61	75	70
Reduction in computed A-weighted level										
H-154 headsets	8	12.5	9.5	10.5	10.5	9	21.5	19.5	12.5	13
V-51R earplugs	9	27.5	26	26	26.5	25	30.5	29.5	28	27.5

The data shown in table II indicate that the shape of the noise spectrum influences the amount of attenuated A-weighted levels obtained. The highest values of attenuation for equivalent A sound levels were obtained for the two spectra representative of fixed-wing aircraft powered by either turbojet or turbofan engine (J-Int, J-ext).

Figure 4 is a scattergram which illustrates the relationship between C minus A values and the reduction in A-weighted level "at-the-ear" with H-154 headsets and V-51R earplugs. The trend that appears indicates that the smaller the C minus A value, the more effective is the ear protection in reducing the A-weighted level "at-the-ear." Conversely, the greater the C minus A value, the less effective will ear protection be in reducing "at-the-ear" A-weighted level. The relationships discussed here are based on knowing both C- and A-weighted levels for a given noise. The A-weighted level alone provides a poor basis for estimating "at-the-ear" A-weighted level when ear protection is worn. The reduction in computed A-weighted level, lines 8 and 9, table II, ranges from 9 to 30.5 dB for the types of aircraft included in this report. Observations such as these are expected to lead to auditory damage-risk criteria based on a combination of C- and A-weighted levels, so that risk can be assessed for a specific noise condition with both protected and unprotected ears.

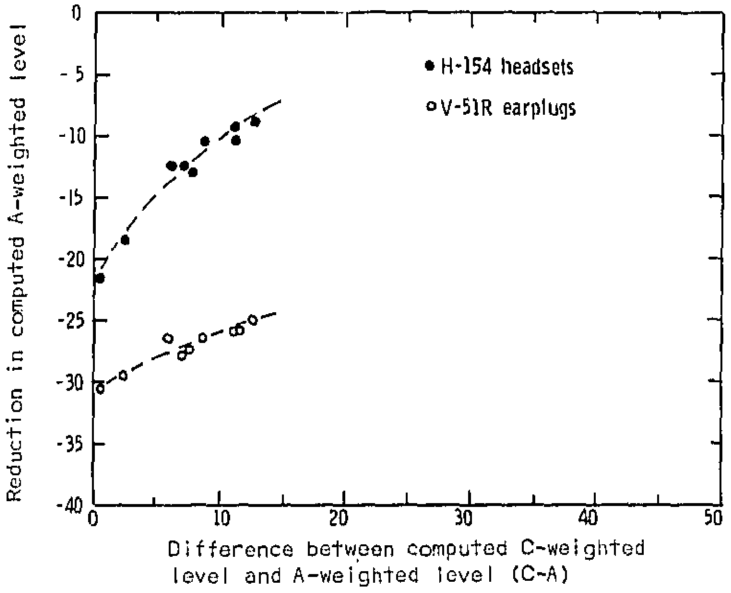

FIGURE 4

Attenuated A-weighting values for two protective devices (H-154 headsets and V-51R earplugs) for different values of C-A.

IV. SUMMARY AND CONCLUSIONS

Mean spectra of noise measured in eleven groups of fixed- and rotary-wing aircraft during conditions of normal cruise were used to establish unprotected and protected values of A-weighting. The attenuated and nonattenuated values of A-weighting, when correlated with C-A values, indicate that small values of C-A yield greater amounts of attenuation than higher values of C-A. For example, a C-A of 0.5 yielded a mean attenuated A-weighted value of 21.5, and a C-A of 12.5 provided a mean attenuated A-weighted value of only 9 dB.

The results derived from this study indicate that, for noise spectra encountered within cockpits, C-A values can be used to estimate varying amounts of attenuation provided by personal ear protection devices when corrected for equivalent attenuated A-weighting values.

The ultimate value of A-weighted measurements will depend on research of the type reported in this study.

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A-scale Auditory risk criterion Auditory risk limits Damage risk (auditory) Noise-induced hearing loss Hearing conservation						