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DEVELOPMENT OF REALISTIC A-WEIGHTED AUDITORY RISK CRITERIA FOR AEROSPACE OPERATIONS

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FOREWORD

The work contained in this report was conducted in the Audiology and Hearing Conservation Function of the Otolaryngology Branch under task No. 775508 during the period November 1970 to August 1971. The manuscript was submitted for publication on 7 October 1971.

This report has been reviewed and is approved.

EVAN R. GOLTRA, Colonel, USAF, MC
Commander

ABSTRACT

The authors have previously proposed adoption of the CHABA Working Group 46 criterion for steady-state noises to assess degrees of auditory risk associated with aerospace operations. In this report, the salient features of various damage risk criteria are reviewed and primary and secondary compromises are discussed. A simple criterion using A-weighted sound levels is proposed for broad-band and narrow-band steady-state and intermittent noise and for impact noises. The criteria contained in this report provide guidance needed to identify potentially hazardous exposures encountered in aerospace operations.

DEVELOPMENT OF REALISTIC A-WEIGHTED AUDITORY RISK CRITERIA FOR AEROSPACE OPERATIONS

I. INTRODUCTION

The need for a simple measure of ambient noise that can be correlated with degree of auditory risk has prompted audiologists to adopt a unit of measure based on the A-weighting network of a sound-level meter. This unit, the dBA, has received considerable acceptance--the U. S. Department of Labor (14, 22, 28, 30); the American Conference of Governmental Industrial Hygienists (17, 18); the American National Standards Institute (13); the American Industrial Hygiene Association (19); and others (5-7, 24-27)--but agreement has not been reached on how the unit can be equated with auditory risk.

Several attempts have been made to evaluate the practicality of the use of dBA in specific noise environments (1-5, 9-11, 16, 24, 27). In a comparison (12) of dBA criteria proposed by various investigators, the authors pointed out the need for caution in the initial phase of its application. Many of the dBA criteria currently proposed yield estimates of auditory risk (specified in duration of allowable exposure) that differ considerably from one another (12).

One problem is that the criterion contained in the Occupational Safety and Health Act of 1970 (Walsh-Healey) yielded estimates of auditory risk which are considerably more lenient than those contained in the proposal of the CHABA Working Group 46 (12). Therefore, managers of hearing conservation programs should exercise caution when attempting to apply auditory risk limits of the Walsh-Healey Act. Of the two methods contained in the Walsh-Healey Act for assessing hazardous noise, the tangent-to-the-curve method is less stringent than the basic dBA method.

CHABA Working Group 46 considered that their set of criteria would allow for some degree of noise-induced hearing loss--about the amount to be expected in individuals who encounter noise routinely over the period of a worklife. Therefore, criteria which are obviously more lenient must be regarded with extreme caution.

A previously mentioned study by the authors (12) revealed that the dBA criterion proposed by Botsford (5), in which a correction factor "C minus A" was used, yielded risk limits that are slightly more stringent than that of CHABA Working Group 46. Also, the dBA criteria proposed by Parrack (24), and Gasaway and Sutherland (9), and the dBA contour that was considered by ANSI (25), yield estimates of allowable exposures which are more conservative than those obtained using the CHABA criteria.

The AFR 160-3 criterion, when converted to dBA, closely parallels that of CHABA. Apparently, the dBA criterion of Pfander (27), which employs a linear trade of 4 dBA for each halving or doubling of noise duration, and of AFR 160-3, which allows a linear trade of 3 dBA for each halving or doubling, offer estimates of auditory risk that may prove of value.

Two elements add to the complexity of applying dBA: (a) The relationship between durations of noise exposure and resulting temporary and permanent noise-induced hearing loss appears to be a curvilinear rather than a linear function (33), and (b) the spectrum content of a given noise influences the degree of auditory risk associated with the noise. Although differences in spectral content may be adjusted by employing a correction factor such as "C minus A" (5, 11, 24), use of such a factor increases the complexity of the task of assessing auditory risk.

The primary task which now confronts medical monitors consists of making the dBA measurement compatible with operational needs and of correcting deficiencies which preclude its ease of use and validity.

The authors' concern that use of 90 dBA for assessment of auditory risk boundaries was not stringent enough for Air Force personnel was recently substantiated by Kryter (21). It appears that a misinterpretation of normative hearing data led to the adoption of too lenient a risk limit (90 dBA) that, if followed, would lead to a greater incidence of noise-induced hearing loss among persons who routinely encounter noise above 90 dBA. The incidence of noise-induced hearing loss among military and civilian Air Force personnel was considered significant enough that any auditory risk criterion proposed for Air Force adoption should be equally as stringent as that currently employed. A less stringent criterion cannot be accepted. Also, the method of specifying degrees of auditory risk must be operationally feasible and simple to use. Accomplishment of this goal is the intent of this report.

II. APPLICATION OF dBA IN THE MILITARY

Many environments encountered by military service personnel constitute definite noise risks. The need for a simple solution to the problem of identifying the degree of hazard is great. Medical personnel in the military services must attempt to enforce noise exposure standards and the criteria must be simple, yet reliable (12).

Adoption of the dBA for purposes of hearing conservation within the military appears feasible (11, 12, 24). Yet, several problems accompany the use of a single value to describe a complex acoustic event that poses potential risk to the individual. For example, the authors (11) in attempting to solve one of these problems have worked out a method for equating dBA values with attenuation provided by ear protectors. Before this procedure was developed, octave-band noise data were needed as a basis for determining attenuation requirements. Adoption of the dBA measurement must include consideration of ways to facilitate its use. Criteria that are too complicated for use in routine operational situations are of very limited value (2, 3, 8, 9, 12, 24, 31).

The following factors should be carefully considered when establishing auditory risk limits for use in military hearing conservation programs:

1. Although many individuals entering the military establishment can be expected to encounter excess noise for periods ranging only from 2 to 4 years, a large number will remain in the service and be exposed to this environment for 20 to 30 years. Also, many who leave the service will continue working in the same career field (with its attendant noise environment) for possibly another 10 to 15 years. Therefore, estimates of degree of auditory risk must encompass a worklife of 25 to 35 years.

2. Although most estimates of auditory risk presume an 8-hour workday, many individuals receive additional exposures which may represent a considerable risk when totaled for a 24-hour period. When the criteria contained in AFR 160-3 were published in 1956, the primary concern relative to auditory risk centered around the noise encountered at work. Today, as emphasized by many researchers who must attempt to establish auditory risk limits (6, 12, 23, 24), the degree of risk represented by a worklife of noise exposure must consider off-duty activities. This feature is more complicated than it appears on the surface. For example, a jet mechanic must frequently work in very intense noise fields, such as 155 dBA during fuel trimming of a jet engine. Even with an earplug and noise-muff combination, this constitutes a borderline risk. Then, after the engine has shut down, he may mistakenly think that he can remove the protection--at a time when the noise generated by a ground power unit (which may only register 88 dBA) represents a far greater potential risk, in combination with the previous exposure, than it would if experienced alone. In the real world of events, this same mechanic may finish work and then play guitar in a rock band for three or four hours that evening. It is this complexity of sequential episodes of noise exposure that prevents easy application of and adherence to even the most comprehensive auditory risk criteria.

3. The emphasis of the Air Force Hearing Conservation Program is on protecting the hearing of persons who encounter potentially dangerous acoustic noise. This approach is consistent with firm medical management and it must be continued, but, as a result, correlations of unprotected noise exposures with subsequent noise-induced hearing loss will become progressively more difficult to establish (6, 7, 29).

4. Monitoring audiometry must be carefully conducted to insure that noise-induced hearing losses are identified early in an individual's worklife and that subsequent more severe losses are prevented from occurring. Properly conducted and managed audiometric monitoring will insure the validity not only of risk criteria but also of methods of controlling potentially hazardous noise. The need for audiometric monitoring of individuals included in a military or industrial hearing conservation program increases with the degree of emphasis placed on controlling undesirable effects of noise (29). Simply stated, pure-tone threshold monitoring audiometry must be performed on all individuals, military and civilian, who routinely encounter noises (unprotected) that are considered to be potentially hazardous.

For purposes of risk determination, noises can be categorized as: (1) impact, (2) steady state, or (3) intermittent. These groups can be further delineated by spectral content; i.e., whether the spectrum contains broad-band or narrow-band noise components. Each of these types of noise represents a different degree of auditory risk, and different criteria have evolved in an attempt to identify the degree of risk. It is not the intent of this report to discuss the different criteria in detail, but a few generalizations are appropriate:

1. Impact noises are regarded as a potential risk to unprotected ears when levels exceed 140 dB (peak levels re 0.0002 microbar).

2. Steady-state noises lasting from 1 to 480 minutes (8 hours) per day are considered as potentially hazardous when levels exceed about 85 dB within the frequency range of about 300 to 4800 Hz. Also, if the spectrum of the noise contains evenly distributed acoustic energy across these frequencies, then the exposure is somewhat less hazardous than when discrete frequency components are present. Although this difference was previously thought to be as much as 10 dB, later evidence tends to support the contention that the degree of auditory risk represented by pure-tone or narrow-band components should be adjusted by about 5 dB. In other words, a broad-band noise spectrum of 100 dB (octaves 300 to 4800 Hz) would be equivalent to one of about 95 dB (same frequency range, 300 to 4800 Hz) for a noise containing pure-tone components. Of course, certain trades in duration may be accomplished with changes in levels of unprotected exposure. These trades may use 3 dB for each doubling or halving of duration (equal energy concept) (15) or the trades may be up to 6 dB for each doubling or halving of duration (equal pressure concept) (20, 25), or the trades may be somewhere in between, such as 5 dB for doubling or halving of time (13, 19) or 4 dB as proposed by Pfander (27).

3. Intermittent noises constitute degrees of auditory risk that are far more difficult to assess than either impact noises or long-duration steady-state noise. Differences of opinion are great, and specific risk limits are far more difficult to delineate. In any event, it does appear that intermittency, especially when durations of "off" time are in relative quiet (below about 75 dB in octaves 300 to 4800 Hz), constitutes less of an auditory risk (2, 5, 24, 32, 33).

III. ESTABLISHING REALISTIC AUDITORY RISK LIMITS

The authors have investigated the myriad of noises encountered by military and civilian personnel in the Air Force--gunfire, jet engines, helicopter flight, and the like. The study of such operations, together with evaluation of various auditory risk criteria and limits of allowable exposure, has led to the following proposals. The approach is based on considerations stated in section II of this report.

Rationale

Medical monitors of hearing conservation programs must identify all types of acoustic noise that represent potential risk to unprotected ears so that noise control measures can be initiated and enforced. The authors propose that any criterion that is less stringent than that currently employed by the Air Force (AFR 160-3) is not acceptable. Experience with the Air Force Hearing Conservation Program and analysis of hearing data received at the Air Force Hearing Conservation Data Repository indicate that the auditory risk limits used during the past 15 years are appropriate and reasonably valid.

The following proposals are made:

1. Establishment of a risk limit of 85 dBA (slow meter action) for broad-band and 80 dBA for narrow-band continuous, steady-state, acoustic exposures lasting from 1 to 480 minutes per day for a 5- to 6-day workweek for a worklife of 25 to 30 years.

2. A "trading relationship" of 3 dBA for each doubling or halving of duration (in minutes) for noises of the type identified above. This trade is illustrated in figure 1. The following rule of thumb, for example, can be used to determine durations of auditory risk for unprotected exposures to steady-state broad-band noise.[1]

Duration in minutes (unprotected)	dBA (at ear)
480 (8 hours)	85
48	95
4.8	105
.48 (less than 1 min.)	115

3. For intermittent noises, the limit should be raised to 90 dBA (slow meter action) for unprotected exposures to broad-band noise and reduced to 85 dBA for exposures to narrow-band noise. When levels are known or suspected to exceed these limits, emphasis should be placed on using personal ear protection when noise is "on."

4. Noises which are known to contain pure-tone or narrow-band components at levels that exceed 85 dB, or 90 dBA as appropriate, should be considered slightly more hazardous than noises that do not contain such discrete acoustic components. In such instances, enforcement of ear protection should receive extra emphasis.

5. Impact noises should be considered as potentially hazardous to unprotected ears when peak levels (C-weighted, all pass, or flat) are known to exceed 140 dB (re 0.0002 microbar) (20). When levels are known

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[1]The appendix provides detailed limits of auditory risk for four types of nonimpact noises.

or suspected to exceed 140 dB, effort should be expended to insure use of personal ear protection. Generally, this limit can be enforced by considering that gunfire noise emitted by virtually any firearm other than a .22-caliber rifle is potentially hazardous and ear protection is required.

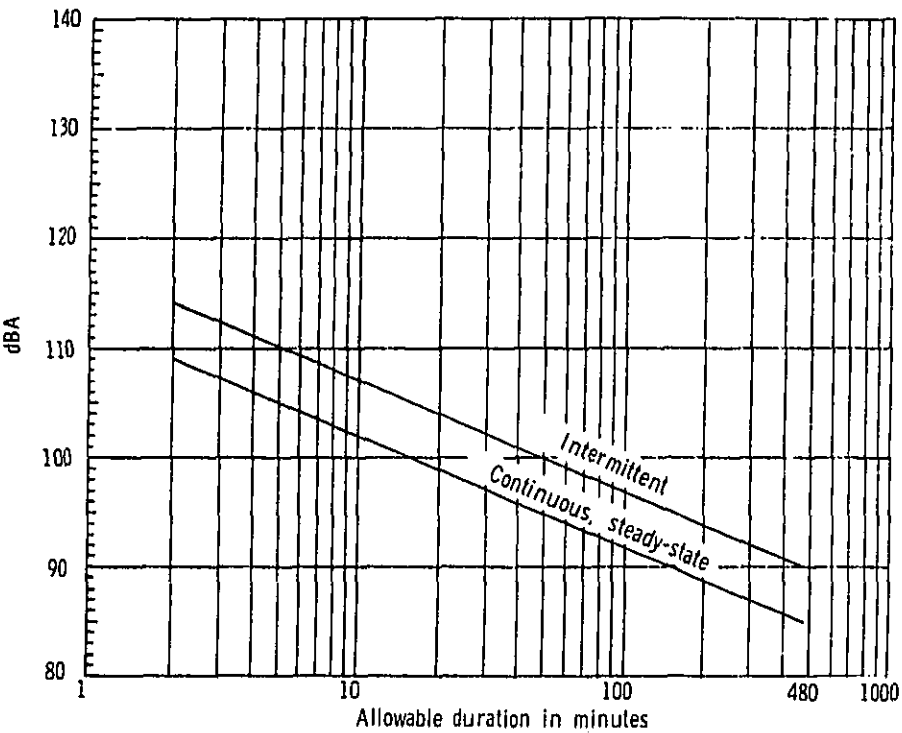

FIGURE 1

Damage risk limits in dBA for continuous and intermittent noise exposure.

Table I provides a brief review of the auditory risk limits proposed. The ease with which these limits can be used for conditions of protection, assuming standard earplugs (V-51R) <u>or</u> noise muffs (David Clark model 117) or both plug <u>and</u> muff conditions, is evident. The amounts of attenuation expected from standard devices currently used by the Air Force have been generalized so that use of either a plug <u>or</u> muff will provide 20 dB of attenuation (equivalent dBA) and use of combination devices (plug and muff) will provide attenuation of 30 dB, an increment of 10 dB (equivalent dBA). The left column identifies the five different conditions of auditory risk described in this report. The second through fourth columns identify levels of allowable noise measured using the A-weighted circuit of a sound-level meter. The last column identifies allowable durations of time (in minutes) appropriate for each condition cited. For example, a particular noise environment that is steady-state and contains pure-tone components that measure 110 dBA constitutes an auditory risk for durations of less than 1 minute for unprotected ears; but if the individual wears either a standard earplug or noise muff, the allowable durations can be increased to 48 minutes per day, and if both plugs and muff are worn, the allowable duration becomes 480 minutes per day (8 hrs).

TABLE I

Summary of unprotected and protected auditory risk limits
(see the appendix)

Type of noise	Unprotected	Allowable dBA when protected Plug or muff	 Plug and muff	Allowable time (min.)
Steady-state, continuous, no pure-tone component	85 dBA	105	115	480 min/day
	95	115	125	48
	105	125	135	4.8
	115	135	145	less than 1 min.
Steady-state, continuous, with pure-tone component(s)	80	100	110	480
	90	110	120	48
	100	120	130	4.8
	110	130	140	less than 1 min.
Intermittent, no pure-tone component(s)	90	110	120	480
	100	120	130	48
	110	130	140	4.8
	120	140	150	less than 1 min.
Intermittent, with pure-tone component(s)	85	105	115	480
	95	115	125	48
	105	125	135	4.8
	115	135	145	less than 1 min.
Impact (peak levels)	140	160	170	ALWAYS WEAR EAR PROTECTION

NOTE: Allowable limits specified above are contingent on receiving adequate ear protection.

Implementation

To implement the above approach, the following steps must be taken:

1. Establish boundaries for appropriate upper risk limits (as previously described) for 480 minutes per day, with a trade of 3 dBA for each doubling or halving of noise duration. This standard is at least as stringent as the current set of criteria used by the Air Force, and is considerably more stringent than that specified in the current Occupational Safety and Health Act — a standard which has already been recognized as inappropriate for a worklife of exposure.

This criterion can easily be used by medical monitors or by noise-exposed personnel. It is not practical to issue noise-measuring instruments to every organization or individual, and even if such instruments were provided, the individual could not be expected to use them in all situations where noise hazards exist. Neither can noise dosimetry be used with any degree of success. Nevertheless, persons (unprotected) can be cautioned that when they must use a loud voice at a distance of 1 ft. or a shout at 3 ft. to communicate in the presence of interfering noise, then they are in a potentially hazardous noise environment.

If levels exceed the boundaries previously described as appropriate but are less than about 110 dBA, there is little need to figure details of allowable durations, because use of ear protection devices is mandatory and will probably provide adequate protection for durations up to 8 hours per day.

If levels are found to exceed about 110 dBA, then durations of allowable protected exposure must be computed with consideration given to the amount of noise that still reaches the ear. The authors have already provided a technique that can be used to determine equivalent amounts of attenuation for A-weighted levels of exposure (11).

These considerations provide limits of allowable duration which must be enforced in conjunction with the use of personal ear protection. Emphasis should be given to careful audiometric monitoring of individuals who routinely encounter noises that compromise exposure limits; i.e., when levels are great enough that the degree of noise attenuation achieved with a protective device is insufficient. When situations are suspected, three alternatives must then be considered: increased protection, decreased duration of exposure, and stringent audiometric monitoring.

2. Since even the most vigorous efforts of researchers to determine degrees of auditory risk represented by intermittent noise have failed to provide valid assessments, the authors have approached this most difficult problem from an operational point of view. This approach is to educate personnel to use ear protection when such noises are encountered. Although this seems too simple, it constitutes the single most successful approach to the problem.

3. Adequate evidence exists that noise which contains pure-tone or narrow-band components should be considered slightly more hazardous than equivalent levels of noise that do not contain such discrete frequency components. Generally, the human ear can easily perceive the presence of discrete noise components; so, once again, the individual should be the ultimate evaluator. Once such a noise hazard is recognized or even suspected, the use of personal ear protection can be emphasized. Operationally, medical monitors can emphasize the stringent need for use of ear protection by employees and others working in noise-hazardous areas.

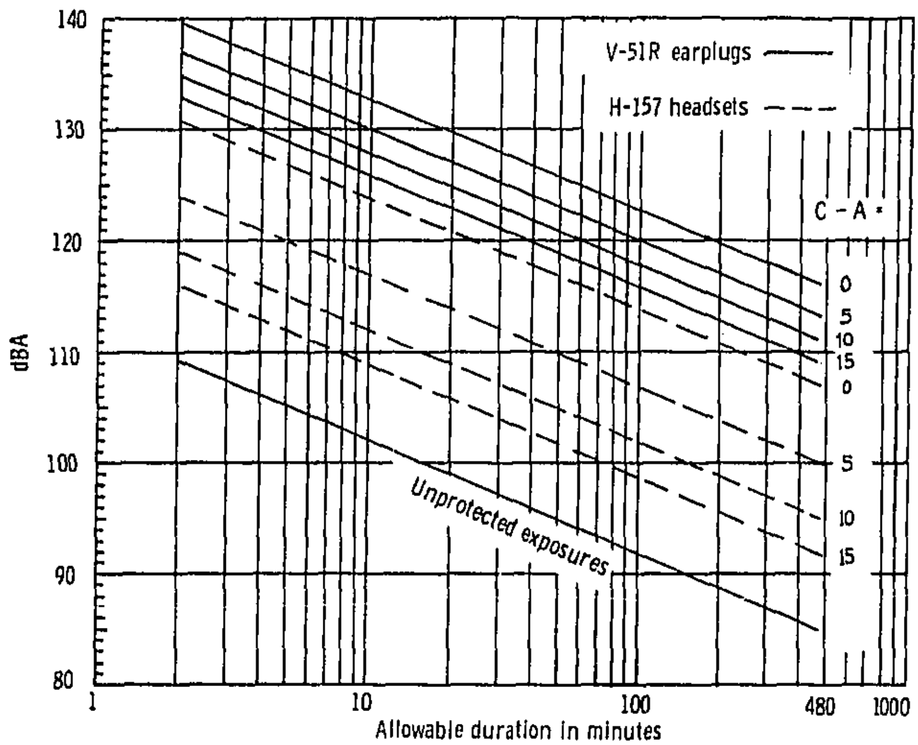

FIGURE 2

Damage risk limits for noises with various C—A values with V-51R earplugs and H-157 headsets.

4. Although potentially hazardous noise exposures can be readily recognized by using dBA, the nature of the A-weighted network is such that care must be exercised when attempting to determine the amounts of attenuation provided by personal ear protectors. Since most protective devices (headsets, earplugs, noise muffs, etc.) provide less attenuation in the lower range of frequencies, an inverse relationship may exist between attenuation and the frequency weighting characteristics of dBA. A simple method has been described by the authors for use in determining amount of equivalent A-weighting to be expected when ear protection devices are worn (11). By using measured C- and A-weighted levels, the attenuated A-weighted levels can be determined. Figure 2 illustrates attenuated A-levels computed for two different ear protection devices: V-51R earplugs and H-157 headsets. For example, an ambient noise that rendered an A-level of 110 dBA and a C-level of 100 (a difference of 10 dB between dBA and dBC) would permit an allowable duration of 15 minutes if standard headsets were worn. (Read across the diagonal line identified by "C—A = 10" for the H-157 headset until 110 dBA is intersected, and then read the allowable duration noted below.) The authors are currently preparing sets of attenuated A-level charts for various types of personal ear protection devices so that different degrees of auditory risk can be readily determined.

Very generalized attenuation conditions have been used here for purposes of illustration and simplicity; hearing conservationists may have to evaluate degrees of auditory risk in a more definitive manner. Use of C—A as the method of accomplishing this task appears more appropriate.

Figure 3 provides a summation of the criteria proposed by the authors for risk limits for both protected and unprotected noise exposures (see table I). Lines A, B, and C represent risk limits for unprotected exposures. Line A applies to steady-state, continuous noise that contains pure-tone or narrow-band components; line B applies to wide-band steady-state continuous noise and also to intermittent noises that contain pure-tone or narrow-band components; line C applies to broad-band intermittent noises. Lines D through H represent risk limits for protected exposures. Lines D, E, and F provide appropriate limits when either earplugs or noise muffs are worn. These lines correspond to unprotected limits identified by lines A, B, and C, respectively; i.e., the limits of line A become those identified by line D when plugs or muffs are worn. Similarly, lines F, G, and H represent limits of exposure when combination protection (plugs <u>and</u> muffs) is worn. (Note that line F represents protected limits for plug or muff applicable to unprotected line C, and line F applies to unprotected limits of line A when plug and muff are used.)

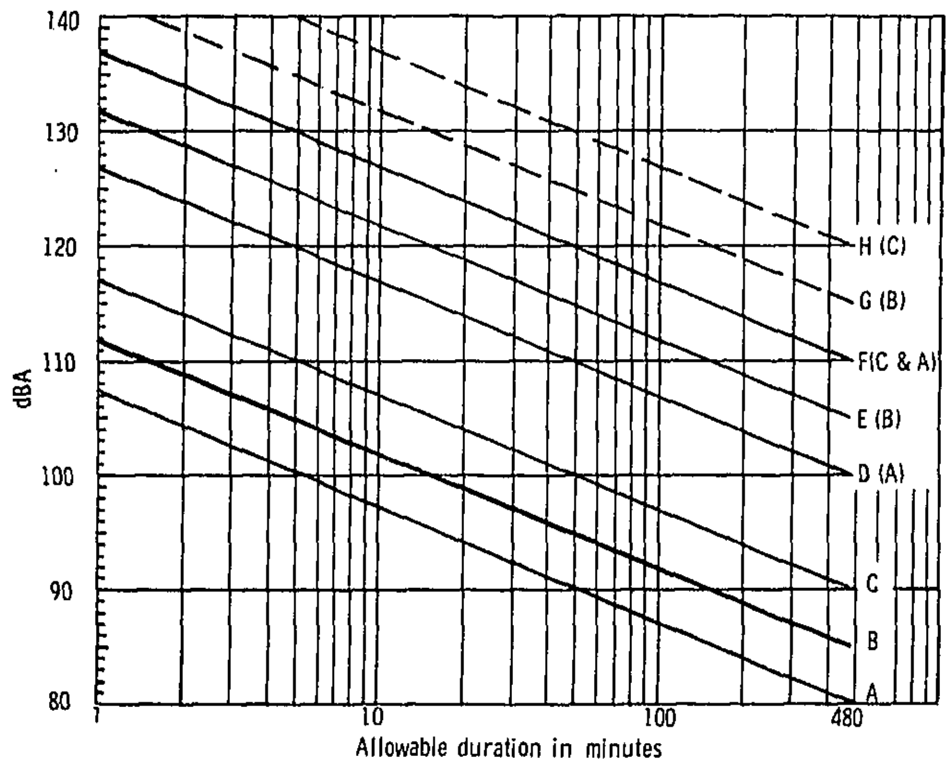

FIGURE 3

Damage risk limits in dBA for continuous and intermittent noises, including those containing pure-tone (narrow-band) components for both protected and unprotected exposures (see text).

IV. SUMMARY AND CONCLUSIONS

A hearing conservation program in the military service requires identification and definition of the various types and degrees of auditory risk. Primary emphasis is on the development of awareness and discipline in each individual who encounters hazardous noise. The variety of situations in which such noise is encountered makes it imperative that all types of exposures, whether associated with duty or off-duty activities, must be easily identified and recognized by the recipient, and he must know what action to take to protect himself. This approach places emphasis on a comprehensive and intensive program of indoctrination of all individuals who are expected to encounter potentially hazardous noise.

A comprehensive program of hearing conservation will contain six elements:

1. Instruction of personnel who will be exposed to potentially hazardous noise.

2. Assessment of hazardous noise duties and areas, and application of auditory risk criteria.

3. Issuance of personal ear protection devices and monitoring use of such devices to insure that hazardous exposures are controlled to the fullest extent possible. Frequently, additional noise control measures must be enforced to accomplish this goal.

4. Audiometric threshold monitoring of all individuals who routinely encounter hazardous noise. With each individual used as his own control, changes in hearing that possibly result from noise can be readily and expeditiously identified.

5. Initiation and maintenance of individual medical records. Medical monitors must have comparative hearing data available on each person so that changes in hearing due to noise can be easily identified.

6. Establishment of medical and administrative disposition procedures to insure that persons who do exhibit losses in hearing receive dispositions which guarantee that significant losses in hearing (losses within the speech hearing range from 500 through 2000 Hz) do not occur. If such losses appear to be developing, then the individual will be removed from noise exposures that may cause further deterioration in hearing.

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APPENDIX

DURATIONS OF ALLOWABLE AUDITORY RISK FOR UNPROTECTED EXPOSURES (IN dBA)

Duration	Steady-State Continuous		Intermittent	
(in min.)	Broad Band	Pure-Tone Components	Broad Band	Pure-Tone Components
480	85	80	90	85
390	86	81	91	86
300	87	82	92	87
240	88	83	93	88
190	89	84	94	89
150	90	85	95	90
120	91	86	96	91
96	92	87	97	92
76	93	88	98	93
60	94	89	99	94
48	95	90	100	95
38	96	91	101	96
30	97	92	102	97
24	98	93	103	98
19	99	94	104	99
15	100	95	105	100
12	101	96	106	101
9.6	102	97	107	102
7.8	103	98	108	103
6.0	104	99	109	104
4.8	105	100	110	105
3.9	106	101	111	106
3.0	107	102	112	107
2.4	108	103	113	108
1.9	109	104	114	109
1.5	110	105	115	110
1.2	111	106	116	111

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11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY USAF School of Aerospace Medicine Aerospace Medical Division (AFSC) Brooks Air Force Base, Texas 78235

13. ABSTRACT

The authors have previously proposed adoption of the CHABA Working Group 46 criterion for steady-state noises to assess degrees of auditory risk associated with aerospace operations. In this report, the salient features of various damage risk criteria are reviewed and primary and secondary compromises are discussed. A simple criterion using A-weighted sound levels is proposed for broad-band and narrow-band steady-state and intermittent noise and for impact noises. The criteria contained in this report provide guidance needed to identify potentially hazardous exposures encountered in aerospace operations.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Auditory damage risk						
Hearing conservation						
Undesirable effects of noise						
Hazardous noise						
Noise control						
Criteria-damage risk						

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