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DESIGN STANDARDS FOR NOISE: A REVIEW OF THE BACKGROUND AND BASES OF MIL-STD-1474(MI)

Georges R. Garinther, et al

Human Engineering Laboratory
Aberdeen Proving Ground, Maryland

March 1975

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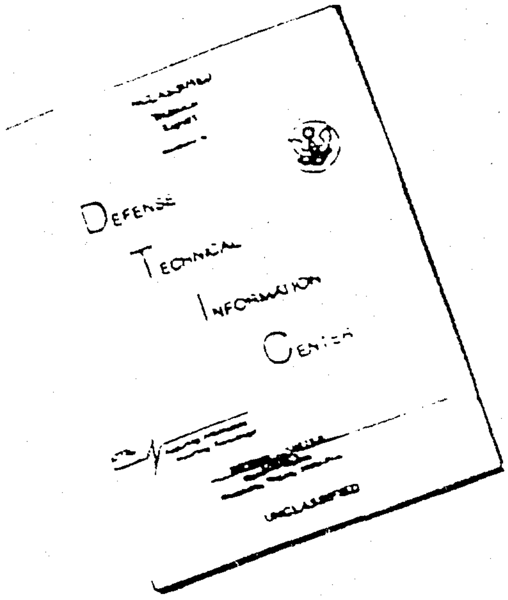

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Georges R. Garinther
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March 1975
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HUMAN ENGINEERING LABORATORY

ABERDEEN PROVING GROUND, MARYLAND

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U. S. Army Human Engineering Laboratory (HEL) Standard S-1-63C (September 1972) was the first design standard for noise in which all previous conflicts between U. S. Army medical guidelines and materiel design criteria were resolved. Its lineal descendent, MIL-STD-1474(MI) (March 1973), was the first design standard for noise in which all Army review activities concurred. This report treats the historical background of Army noise standards, the bases for the noise-limit provisions of MIL-STD-1474(MI), and considerations underlying the specified noise measurement procedures. Appendixes credit the many personnel involved, and an extensive list of references is provided.

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DESIGN STANDARDS FOR NOISE:

A REVIEW OF THE BACKGROUND AND BASES OF MIL-STD-1474(MI)

INTRODUCTION

Two major accomplishments have occurred in the past three years in the area of noise standards for Army equipment. In September 1972, the C-revision of the U. S. Army Human Engineering Laboratory's (HEL) Standard S-1-63 was published; in that document all previous conflicts between medical hearing conservation guidelines and materiel design standards were resolved. In March 1973, Military Standard 1474(MI) was published; that document was the first design standard for noise in which all Army review activities concurred. As of this writing (January 1975) the A-revision of MIL-STD-1474(MI) has been prepared, based on a year of using the Standard, coordinated among the review activities, and will be published shortly.

This report was prepared for two reasons. First, we thought that there should be recorded for posterity a history of the major events which led up to these recent accomplishments. All too often such records are not kept, and users of standards encounter them without getting any appreciation for the evolutionary nature of such documents. Second, we felt that it might be helpful to users of MIL-STD-1474(MI) to have a relatively thorough exposition of the background and bases for its provisions. Military standards and specifications are, by their nature, very concise: they tell you "what" to do, but usually don't tell you "why." Often, standards contain no references that would enable the inquisitive user to reconstruct the bases for their provisions. Also, when the time comes to revise a standard, the bases may have faded from memory, and there may be a tendency to "reinvent the wheel."

This report is divided into three major sections, treating (1) the historical background of Army noise standards, (2) the bases for the noise-limit provisions of MIL-STD-1474(MI), and (3) considerations underlying the specified noise measurements procedures. A final, short, section enumerates major changes that have been incorporated into the A-revision of MIL-STD-1474(MI). Appendixes credit personnel involved in coordinating the Standard, and an extensive list of references is provided.

HISTORICAL BACKGROUND OF ARMY NOISE STANDARDS

Noise Standards Before 1963

Prior to 1963, there was no uniform method within the U. S. Army for establishing acoustical design criteria for a new piece of materiel. Data from various sources were used (3, 27, 48), but these varied considerably and, due to the noise exposure parameters involved, were open to diverse interpretation. The development and use of noise limits prior to 1963 is described below by examining typical cases and problems.

Basic Procurement Instructions

In most instances, provisions imposed on the noise of Army materiel developed during the late 1950's were extremely sparse and stated in very general terms. In fact, such provisions were frequently limited to "boilerplate" type contract clauses such as the following:

> The human factors engineering will include, but not be limited to a consideration of each of the following (where applicable), in terms of the intellectual, physical, and psychomotor capabilities of the intended user: . . . . Environmental factors such as temperature, humidity, dust, noise, vibration, blast.

OPI 7-381 (45) required that the above provisions be inserted in both fixed price and cost reimbursement type research and development contracts which involved man as an element in the operation and maintenance of Ordnance Corps items. Occasionally, this provision found its way into program requirements which implemented such scopes of work. Rarely was it expressed as a quantified design criterion. Virtually never was it imposed in terms of comprehensive criteria to include quantified noise limits, instrumentation and measurement requirements.

Steady-State Noise

During the 1950's, steady-state noise requirements such as, "Noise levels shall not exceed 90 dB," were prevalent. With the benefit of hindsight, it is easy to see that invoking such provisions did not exactly inspire mutual understanding of noise limits between requiring and performing organizations. Consequently, comprehensive noise limits and measurement procedures tended to emerge on an *ad hoc* basis, i.e., as noise problems arose, provided the problems were so potentially serious as to pose a threat to system safety or system effectiveness as defined by other requirements.

Early attempts to provide more comprehensive noise limits were not altogether successful. For example, the limits shown in Table 1 were selected in 1960 for the design of a turbine-powered generating and cooling subsystem. These limits were adapted from Kryter (27) and included a 100 percent safety factor for exposure time, i.e., exposure time was considered to be double the subsystem's possible running time (as derived from fuel capacity) which, in turn, was well above the anticipated mission time. Subsequent events demonstrated that even this degree of conservatism in estimating exposure time was ill-founded, when it was discovered that training units were replenishing their fuel supply on a continuous basis to enable full and uninterrupted utilization of the training day.

Despite the prediction problem noted above, prescribing noise limits by exposure time began to be fashionable by 1961. An example of this approach, extracted from ABMA-STD 434 (39) appears in Table 2. This approach was convenient to use for design specifications and for procurement documents. All the developer needed to do was to determine the daily exposure time (which was typically requested from the user organization). Unfortunately, such exposure time forecasts, which were made at the time the requirements package was being assembled--i.e., at the beginning of development programs--provided even less precision than the approach cited in the previous paragraph. On the other hand, this approach did establish a uniform noise limit for an Army materiel commodity area.

TABLE 1

Example of a 1960 Tailored Noise Limit

Octave Band Limits (Hz)	Band Pressure Level (dB)
20-75	130
75-150	120
150-300	110
300-600	99
600-1200	98
1200-2400	98
2400-4800	91
4800-10kHz	104

Adapted from Ref. 27.

TABLE 2

Example of a 1961 Exposure-Time-Forecast Noise Limit

Sound pressure levels

The maximum allowable sound pressure levels in decibels re:0.0002 microbars to which personnel may be exposed are as follows:

Octave Band Limits (cps)	8 hr/day	4 hr/day	2 hr.day	1 hr/day	30 min/day	15 min/day
20-75	120	120	130	130	130	130
75-150	110	116	122	128	130	130
150-300	100	106	112	118	124	130
300-600	89	95	101	107	113	119
600-1200	88	94	100	106	112	118
1200-2400	88	94	100	106	112	118
2400-4800	81	87	93	99	105	111
4800-10000	94	100	106	112	118	124

If pure tones or critical bands of noise are present in the noise, the maximum allowable sound pressure level in decibels re:.0002 microbars is ten (10) decibels less than the value indicated above where the pure tone or critical band is found.

From Ref. 39.

Communications Criteria

Throughout this period, noise limits intended to ensure efficient communications were typically prescribed by the levels shown in Table 3, extracted from ABMA-STD 434 (39). These levels embody both speech communication and annoyance considerations and were derived from the Noise Criteria (NC) 60 curve. These limits tended to be applied only to those situations involving transmission and reception of critical information; moreover, they were generally applied only to interior noise levels. This was a narrow approach, but it did establish uniform communication criteria for an Army materiel commodity area.

TABLE 3

Example of a 1961 Communication-Based Noise Limit

The interior noise levels in vans, huts, etc., in which communication of information, either electrically or person-to-person, is critical, should not exceed the following levels:

OCTAVE BAND LIMITS IN CPS	OCTAVE BAND LEVEL IN DB re:0.0002 µbar
20-75	79
75-150	73
150-300	68
300-600	64
600-1200	62
1200-2400	60
2400-4800	58
4800-10000	57

From Ref. 39.

Impulse Noise

Before 1963, impulse-noise limits were not ordinarily prescribed for materiel design, although a few specific applications did witness the occasional surfacing of brief, quantitative limits on peak pressure level, e.g., "150 dB maximum," "140 dB maximum," or "135 dB in the ear canal." Duration requirements for impulses were seldom seen, and measurement methods, instrumentation and other important provisions (as we know them today) were rarely mentioned.

Human Engineering Laboratory Noise Standards, 1963-1971

HEL S-1-63 and S-1-63A

In 1963, HEL developed its first noise standard which, it was hoped, would assist project managers, contract personnel, and designers in establishing the maximum acceptable steady-state noise level permitted at personnel-occupied spaces of U. S. Army Material Command (USAMC) equipment. The design limit was a compromise between the then state-of-the-art equipment noise levels and the most current hearing damage risk criterion (DRC) which was shortly to be published by Working Group 46 of the NAS-NRC Committee on Hearing, Bioacoustics and Biomechanics (CHABA) (29). The limit was based on several assumptions which, at that time, were considered to be appropriate:

a. Hearing protection would be worn at least part of the time by personnel operating intense noise sources such as turbines, tanks, missile systems, etc.

b. Soldiers were, in the main, on active duty for less than three years, and research data indicated that higher exposures could be tolerated when the total exposure period was less than the 10 years or so stipulated in the CHABA steady noise DRC.

c. Personnel would not be exposed to equipment noise every day; therefore, their hearing mechanisms would have plenty of time to recover between exposures.

d. USAMC equipment is normally operated for considerably less than the 8 hours per day that is typical of industrial work settings.

Taking all of these considerations into account, the design limit shown in Table 4 was computed so that an extremely unlikely 8-hour daily exposure would not produce an average temporary threshold shift (TTS) exceeding the values shown in Table 5. The permissible average TTS based on the CHABA steady noise DRC (29) is also shown, in column 3 of Table 5, for comparison.

TABLE 4

Maximum Acceptable Steady-State Noise Level
for Army Materiel Command Equipment
(1963-1971)

Frequency Bands (CPS)	Noise Level (dB re 0.0002 microbar)
37.5 - 75	120
75 - 150	115
150 - 300	109
300 - 600	101
600 - 1200	93
1200 - 2400	89
2400 - 4800	89
4800 - 9600	91

From Ref. 42.

TABLE 5

Permissible Temporary Threshold Shift (dB)
for an 8-Hour Noise Exposure

Frequency (Hz)	HEL S-1-63 (Ref. 42)	CHABA WG-46 (Ref. 29)
≤1000	22.5	10
2000	30	15
≥3000	30	20

The first HEL noise standard (HEL S-1-63) was published in October 1963 (42). A second version (HEL S-1-63A), in which only the scope was slightly changed, was published in June 1964 (43). In the intervening period, maximum allowable sound pressure levels (SPLs) at personnel occupied spaces of Army missile systems were imposed (January 1964) by MIL-STD-1248(MI) (13) with reference to HEL S-1-63. MIL-STD-1248(MI) also expressed an NC-60 maximum noise level for the communication of critical information.

HEL S-1-63B

In 1965 is was found necessary to add a noise limit for situations in which non-electronically-aided person-to-person communication was required. The NC-60 level (Table 3) was chosen as the highest permissible level for command and operation areas, communication shelters, etc., where operating personnel would normally be 1-2 meters apart.

By this time, research being conducted at HEL and at other laboratories indicated that it was possible to establish a design limit for certain types of impulse noise, such as that produced by small arms. This limit, shown in Figure 1, assumed that:

a. No more than 100 rounds would be fired per day.

b. The ear would be at grazing incidence to the noise source.

c. Seventy-five percent of the exposed ears would not exceed the CHABA TTS values shown in column 3 of Table 5.

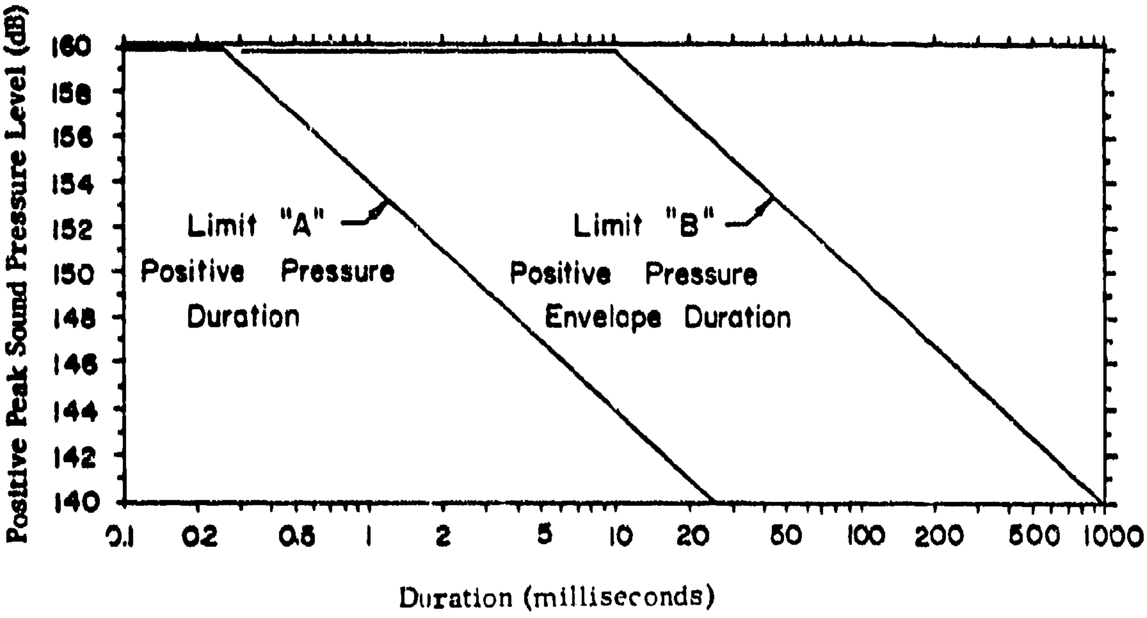

Figure 1. Maximum acceptable impulse noise parameters for Army Materiel Command small arms, 1965-1971. (From Ref. 44.)

At that time, insufficient research had been conducted to permit extension of impulse-noise limits to industrial applications, larger weapons such as shoulder-fired rockets, or fewer numbers of exposures per day. The limits of Figure 1 were found, however, in independent studies conducted by the British, to be very accurate for exposure to the noise of small arms. This similarity of research results was such that a joint report was later prepared by the British and Americans (7).

In 1965, then, HEL Standard S-1-63B was issued with the addition of the communication and impulse-noise requirements (44).

Following the issuance of HEL S-1-63B, MIL-STD-1472 (14) was approved by the Department of Defense (9 February 1968) and made mandatory for use by all departments and agencies. For speech communication, MIL-STD-1472 specified maximum noise levels as NC-30 to NC-70 for various types of work areas. For hazardous noise of Army materiel (excluding aircraft) it specified that the limits of HEL S-1-63 should not be exceeded. For aircraft noise levels, MIL-A-8806 (12) was referenced.

Office of the Surgeon General Guidelines, 1962-1974

TB MED 251 (1965)

The 1956 version of TB MED (Technical Bulletin, Medical) 251, "Noise and Conservation of Hearing," was revised and issued 25 January 1965 (10). This bulletin identified noise levels above which it would be advisable to implement a hearing conservation program. Two alternate criteria were set for continuous noise. The first was a set of SPLs in each of six commercial octave bands, as listed in Table 6. (If pure tones were present--indicated by an octave band level 5 dB or higher than those in the two adjacent bands--then the SPL in the band containing the pure tone was reduced by 5 dB.) The second, or alternate, criterion was an overall SPL (not A-weighted) of 90 dB.

TABLE 6

Octave Band Noise Limits of TB MED 251, 1965

Octave Band Limits (CPS)	Sound Pressure Level (dB)
150-300	92
300-600	85
600-1200	85
1200-2400	85
2400-4800	85
4800-9600	85

From Ref. 10.

For impulse noise, a level of 140 dB peak was set as the maximum recommended exposure for unprotected ears.

If any of these criteria was exceeded, it was recommended that a hearing conservation program be implemented. Guidelines were given for the administration of the medical aspects of such a program, such as selection and fitting of hearing protective devices, audiometric test procedures, etc.

TB MED 251 (1972)

The current version of TB MED 251 was issued 7 March 1972 (11). Here the criteria for establishing hearing conservation programs were changed radically. The new criteria were expressed in terms of A-weighted SPL and patterned after the requirements of the Occupational Safety and Health Act (OSHA) (31). By changing to A-weighted SPL, which is less complicated and more easily obtained than octave band SPL, it was felt that the implementation of TB MED 251 by medical and survey personnel would be simplified. The new criteria were based on the guidelines established by the American Academy of Ophthamology and Otolaryngology (AAOO) (1) and use a 5 dB trading relation between time and intensity, i.e., allowable exposure time is halved for each 5 dB(A) increase in level. Table 7 compares the new provisions of TB MED 251 with those of OSHA. It may be noted that the maximum 8-hour unprotected exposure limit provided by TB MED 251 is 85 dB(A), whereas the OSHA limit is 90 dB(A). The Army limit of 85 dB(A) for an 8-hour unprotected exposure is in close agreement with the 84 dB(A) limit adopted by the Air Force in AFR 161-35 (8).

TABLE 7

Maximum Recommended Sound Level Exposures
to Steady Noise Measured in dB(A)

Exposure Duration per Day (Hours)	Maximum dB(A) TB MED 251 (Ref. 11)	Maximum dB(A) OSHA (Ref. 31)
8	85	90
6	87	92
4	90	95
3	92	97
2	95	100
1-1/2	97	102
1	100	105
1/2	105	110
1/4 or less	110	(ceiling) 115

The impulse noise criterion for establishment of a hearing conservation program was maintained at 140 dB peak SPL.

Again, guidelines for adminstration of hearing conservation programs were elaborated in the revised TB MED 251.

Army Regulation 40-5, "Health and Environment" (9), prescribes a comprehensive preventive medicine program for the Army and areas under its control. This regulation applies to all commands of the U. S. Army, and directs commanders to ensure that all aspects of a hearing conservation program, as defined in TB MED 251, are implemented. It stipulates that levels above 85 dB(A) for steady-state noise, and 140 dB peak SPL for impulse noise, are hazardous to hearing.

During the period 1965-1971, several problems and new acoustical topics arose which, collectively, resulted in a further revision of HEL S-1-63B.

Conflicting Noise Limits

Considerable confusion resulted from the differences in noise limits prescribed by TB MED 251 (a hearing conversation guideline) and HEL S-1-63B (a design standard). Project managers, contractors, and test and evaluation personnel were constantly confronted with two different sets of noise limits against which their acoustical data were being compared. Although these two documents were clearly intended for entirely different purposes and audiences, the constant dilemma about which set of limits to follow made it imperative that a single standard be produced which would bring the design and medical community documents into consonance.

Non-Uniform Equipment Testing

HEL S-1-63B contained only rather sketchy information about how to measure equipment noise for conformance to the stated limits. Frequently, different test agencies would provide acoustical data which were completely at variance. The differences could usually be attributed to one or more of the following:

a. Variations in test conditions, e.g., road surfaces, grades, speeds, loads, etc.

b. Differing instrumentation techniques. This was a particularly critical problem for impulse-noise measurements; e.g., use of transducers having different rise-time characteristics, differences in transducer orientation, types of readout devices, etc.

c. Lack of personnel trained in current techniques of acoustical measurements. Errors included selection of improper microphones for a particular application, overloading instruments, improper calibration techniques, etc.

Aural Security Requirements

Aural security (or, non-detectability) had previously been a requirement for some USAMC equipment, but no design limits or test procedures had ever been developed to assure that such equipment would not be detected by the enemy beyond a specified distance. This lack of precise guidance resulted in equipment being produced which did not meet the user's needs and, in some cases, resulted in lawsuits by contractors because the imprecise requirements were subject to varying interpretation.

Community Annoyance

It became apparent with the passage of the Noise Control Act of 1972 (46) that the USAMC noise standard should contain limits and procedures for use in complying with regulations which would ultimately be issued by the Environmental Protection Agency (EPA). These EPA regulations would apply only to certain classes of equipment, notably those passing through communities frequently, or in large number; combat vehicles, cross country vehicles or equipment procured by USAMC in very limited quantities would not have to comply.

In addition to the technical problems and new topics listed above, a primary stimulus for beginning the revision of S-1-63B at that particular time was a memorandum from the Vice Chief of Staff, U. S. Army (47), directing that a coordinated program be initiated to reduce premature hearing loss in Army personnel. One aspect of such a program was the review and updating of the USAMC equipment design standard for noise.

Preliminary discussion of the revision project began in November 1971, and actual writing commenced in January 1972. The first complete draft was circulated within HEL in March 1972; this resulted in many additional comments, which were incorporated into the draft circulated for comment in USAMC and other DA agencies in June 1972.

At that point, there were still some discrepancies between the provisions of the draft HEL S-1-63C and the 1972 version of TB MED 251 (11). The Surgeon General nonconcurred with the draft, and there followed a series of informal discussion meetings with personnel of the U. S. Army Environmental Hygiene Agency in July 1972. When these discussions became deadlocked over a few key issues, outside consultants of the Surgeon General were called in (Drs. Aram Glorig and W. Dixon Ward), and a consensus was finally reached on all points.

The final version of S-1-63C was published in 1972 (41). This version contained design limits and test procedures for hazardous steady-state and impulse noise, noise in communications areas, and criteria relating to community annoyance and aural security. Since these provisions were mostly carried over to MIL-STD-1474 (see below), discussion of the basis for the provisions is deferred to the section entitled "Bases for Noise Limit Provisions of MIL-STD-1474(MI)" (page 14).

MIL-STD-1474(MI)

In addition to the problems mentioned above, all versions of HEL S-1-63 also suffered from a lack of:

a. Participation by review activities in its preparation, resulting in occasional terminology and interpretation conflicts, as well as administration and application problems.

b. Ready availability from sources familiar to users.

c. Visibility.

d. Understandability by those preparing and monitoring contracts and, where MIL-STD-1472 (14) was not cited, use as a guidance document only.

This latter shortcoming led to situations where HEL S-1-63 could be legally disregarded by contractors when it was made a part of the contract on a non-mandatory basis.

To resolve these problems, coordination of a Military Standard or Military Specification was required. Following the publication of HEL S-1-63C, the resolution of differences with TB MED 251, and in view of the Vice Chief of Staff's memorandum on premature hearing loss, an effort was immediately made to upgrade the provisions of HEL S-1-63C to a limited-coordination (Army) Military Standard. DOD Standardization Project MISC-A867 was initiated on 5 October 1972 to achieve this goal. The U. S. Army Missile Command was selected to serve as the preparing activity for the proposed standard, since that organization was active in the Defense Standardization Program (DSP), and had served as preparing activity for similar DSP documents (e.g., MIL-STD-1428, MIL-STD-1472, and MIL-H-46855), and agreed to undertake the effort on an expedited basis.

The rationale for upgrading HEL S-1-63C to a Military Standard included the following points:

a. Provide a document of higher precedence than the organizational standard.

b. Provide a document that would be more readily accessible to contractors and suppliers, thereby stimulating increased awareness of the noise requirements of Army equipment.

c. Furnish a medium whereby all interested activities could make inputs to the content of the standard in a formal manner.

d. Ensure compatibility of acoustic noise design criteria, and test and evaluation requirements, with procurement practices.

e. Secure more uniform application of maximum noise limits among Army organizations.

f. Serve as a basis for possible tri-service standardization.

g. Provide needed emphasis and visibility to those noise pollution requirements which the Army will have to meet.

The schedule for preparation of the Military Standard called for initiation in the second quarter of FY 73 and completion in the second quarter of FY 74. Due to the importance of the effort, however, USAMC requested expedited handling of the project (Appendix A). Accordingly, MIL-STD-1474(MI) (15) was issued before the end of the third quarter of FY 73.

At the conclusion of coordination with Army review activities, a comment-resolution meeting was held 7-8 February 1973 at HEL. All essential comments were resolved (or withdrawn) and MIL-STD-1474(MI) was published 1 March 1973. Participants in DSP Project MISC-A867, and resolution meeting spokesmen, are listed in Appendix B. The memorandum of agreement among the principal spokesmen appears as Appendix C.

MIL-STD-1474A(MI)

During the comment-resolution meeting on MIL-STD-1474(MI), it was agreed that the first year after publication of the standard would be a "shake-down" period, and those problems arising from the specified noise limits, test procedures and instrumentation techniques would be evaluated. Following this year of assessment, technical discussions would be held for at least six months prior to initiating a revision project. This six month period would provide an opportunity to incorporate necessary changes, reconsider comments withdrawn in the interest of expediting publication of the initial version, and provide a forum for free exchange of technical material, ideas and organizational positions in a manner unencumbered by time and procedural constraints. Such technical discussions took place at HEL on 20-22 March and 21-23 May 1974, and resulted in selection of the material to appear in the circulation draft of MIL-STD-1474A(MI) (Proposed).

After circulation of the draft to review activities and exchange of submitted comments, a formal comment-resolution meeting was held at HEL 10-11 December 1974. (The participants are listed in Appendix D.) As a result of that meeting, MIL-STD-1474A(MI) (16) is in press and is scheduled to be issued in early 1975.

Major changes incorporated into the A-revision are enumerated in the section entitled "Major Changes Reflected in MIL-STD-1474A(MI)," (page 27). At various points in the following two sections, footnotes indicate changes in table and figure designations in the A-revision.

BASES FOR NOISE LIMIT PROVISIONS OF MIL-STD-1474(MI)

Steady-State Noise in Personnel-Occupied Areas

The design limits for steady-state noise in personnel occupied areas are all identified in terms of specific communication requirements in such areas. These limits may be further characterized into two types: those limits based primarily on hearing conservation priorities; and those based primarily on ease of communication. The former limits involve noise levels which could cause loss of hearing (temporary or permanent), whereas the latter limits are for situations where interference with communications is the overriding consideration.

Hazardous Noise, Unprotected Exposure

The basic design limit for unprotected exposure (Category D in Section 5.1 of the Standard) is based on the Surgeon General's (TSG) limit of 85 dB(A) as specified in TB MED 251 (11). This limit, stated in A-weighted SPL, was converted into octave band SPL limits (Tables 2 and 3 of the Standard[1]) which were constructed on an equal-hazard basis and set so that typical equipment noise spectra just meeting the octave band limits of Category D would not likely exceed a sound level of 85 dB(A).

Figure 2 shows several typical U. S. Army equipment noise spectra which have been adjusted to just meet the limits of Category D. The actual A-weighted SPL for each spectrum was calculated; they ranged from 82.5 to 85.2 dB(A). It is estimated that in better than 95 percent of the cases, spectra just meeting the Category D octave band SPL limits will not exceed a sound level of 85 dB(A).

TSG's limit for unprotected noise exposure is based on the hearing handicap[2] risk data of the Committee on the Conservation of Hearing of the American Academy of Ophthalmology and Otolaryngology (1). TSG's position is that 85 dB(A) is the highest unprotected exposure level for which the risk of hearing handicap is acceptable. It may be noted that 85 dB(A) is the unprotected exposure limit recommended by the National Institute of Occupational Safety and Health (26) but not yet adopted by the Department of Labor. It should also be noted that the Army's 85 dB(A) limit is 5 dB(A) lower than the current limits imposed on industry by the Occupational Safety and Health Act of 1970 (31) (Table 7).

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[1] Table 2 in MIL-STD-1474A(MI).

[2] Hearing handicap (or, hearing impairment) relates to the ability to understand conversational speech in a quiet environment (1). Hearing handicap is said to begin when the averaged hearing levels at 500, 1000 and 2000 Hz exceed 25 dB (re ANSI-1969 audiometric zero). Currently, minimizing the risk of hearing handicap is the primary objective of all industrial noise criteria, and some military criteria. Hearing handicap, as defined above, takes no account of hearing acuity at frequencies above 2000 Hz. Eventually, it is hoped, military noise criteria will be revised to preserve soldiers' high-frequency hearing acuity, which is believed to be crucial to certain types of soldiers' performance (25).

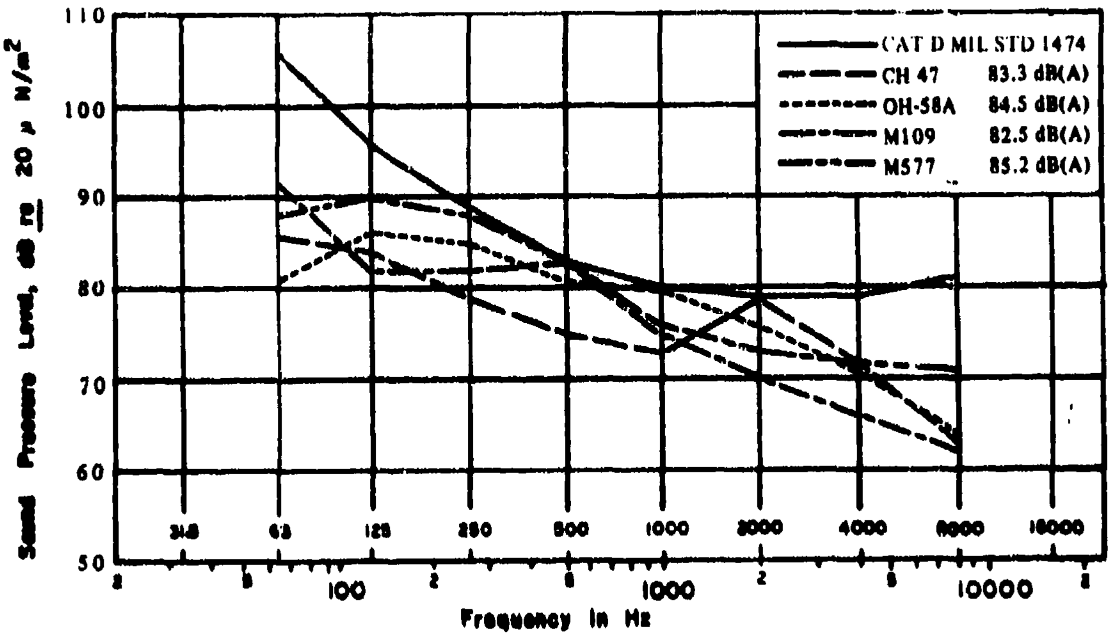

Figure 2. Typical materiel noise spectra which have been adjusted to just meet the octave band limits of Category D, and the resultant A-weighted SPL.

Hazardous Noise, Protected Exposure

Three sets of design limits are provided for protected exposure to steady-state noise. For each, the Standard specifies the degree of communication possible.

a. Category C provides limits which are appropriate when no frequent direct person-to-person voice communication is required. (Intermittent shouted communication may be possible at a distance of 1 foot.) For Category C the octave band limits of Category D were each set 5 dB higher. Inclusion of this category in the Standard permits contracting officers to accept specific limits in situations where it has been determined that Category D is beyond the state-of-the-art, but that Categories B and A are considered to be inappropriate.

b. Category B applies to materiel in which there is a system requirement for communication via attenuating helmets or headsets, e.g., in tanks, armored personnel carriers, etc. For Category B, the octave band limits of Category D were increased by the attenuation values (Table 8) specified in the MN(A) for the new Army armored vehicle crewman's helmet (40). Note, however, that for the upper four octave bands (i.e., starting with the band center frequency of 1000 Hz) the limit specified is 100 dB. This additional consideration was imposed at these frequencies by the limitations of the current family of helmets and headsets so that intelligible communications could be maintained over the intercom and radio systems.

TABLE 8

Attenuation Specified by the Materiel Need for Armored Vehicle Crewman's Headgear, and the Attenuation Actually Provided by the V-51R Earplug

Frequency (Hz)	Attenuation (dB)	
	AVC Headgear (Ref. 40)	V-51R Earplug (Ref. 6)
75	--	24
125	15	23
250	14	21
500	24	23
1000	28	25
2000	30	33
3000	35	34
4000	35	31
6000	35	28
8000	30	30

c. Category A provides design limits which are applicable where there are no requirements for direct person-to-person communication. This is the maximum design limit provided for in the Standard. To derive the limits for Cagegory A, the Category D values were increased by the attenuation of the V-51R earplug (6) as shown in Table 8. The attenuation values of the V-51R were used because they are very close to the average attenuation of all those hearing protectors currently approved for use by TSG.

It should be noted that the limits adopted for all of the design criteria for potentially hazardous noise apply to situations where the daily exposure time will be 8 hours or less. If it can be established that the equipment's mission requirement significantly exceeds 8 hours, then the limits for Categories A, B, C and D must be appropriately lowered.[3] This adjustment, approved by the procuring activity in conjunction with TSG, would follow the rule that a doubling of exposure duration requires a 5 dB decrease in allowable SPL in each octave band. Therefore:

$$SPL_{ADJ} = 85 + 5 \log_2 8/T \quad (1)$$

where T is the anticipated mission time in hours. Note that:

$$\log_2 8/T = \frac{\log_{10} 8/T}{\log_{10} 2} \quad (2)$$

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[3] It should be noted, however, that mission profiles of less than 8 hours per day do not permit the design limits to be raised. The Standard was designed to protect personnel during their total work-day exposure to noise. A generator operator may only need to tend his equipment for 30 minutes per day, but he will not be idle the rest of the time: he may be riding in a personnel carrier, firing his rifle, etc. For this reason the limits in the Standard assume that personnel will normally be exposed to noise for 8 hours per day, unless it is known that the equipment will be operated for longer than 8 hours.

Non-Hazardous Noise

Equipment design Categories E, F and G[4] are based primarily on ease of communication since no hearing hazard is associated with any reasonable length of exposure to the specified noise levels. These categories are based on NC curves (34), which have been developed for use in specifying background noise levels in environments where speech communication and/or annoyance considerations are involved.

a. Category E applies where intermittent electronically-aided voice communication is required via a non-attenuating, binaural (two earphone) headset, or a loudspeaker; where occasional direct person-to-person voice communication is required; but where no telephone use is required. It permits direct communication in a raised voice, without lip-reading, at 1-2 feet, and provides 75 percent monosyllabic word intelligibility. For mobile and transportable systems the noise limits are equivalent to NC 70. For fixed plant facilities, the limits should be reduced to NC-60.

b. Category F applies where frequent electronically-aided voice communication is required via a non-attenuating headset, or a loudspeaker; where frequent direct person-to-person voice communication is required; and where occasional non-attenuating monaural (one earphone) headset or telephone use is required. It permits direct communication in a raised voice, without lip-reading, at 3-4 feet. Again, 75 percent monosyllabic word intelligibility is provided. For mobile systems the limits are equivalent to NC-60. This is reduced to NC-50 for fixed-plant facilities.

c. Category G applies where frequent non-attenuating monaural headset or telephone use is required. For mobile systems the limits are equivalent to NC-55, and are reduced to NC-45 for fixed-plant facilities.

Impulse Noise

Within the Army, impulse-noise exposure refers primarily to weapon noise exposure; e.g., from small arms, rocket launchers, tank guns and howitzers. The development of risk criteria for impulse-noise exposure is much more difficult than for steady noise exposure. One reason is that the population response (i.e., susceptibility to hearing loss) to impulse-noise exposure varies to a much greater extent than is the case with steady noise (19). For example, consider two noise exposures, one steady and the other impulse, with each producing a median TTS of 10 dB at 4000 Hz. The range of TTS for the steady noise exposure would be about 0-29 db, whereas the range of TTS for the impulse-noise exposure would be from -15 dB [negative TTS or an apparent improvement in hearing acuity (23)], to 60 dB temporary loss of sensitivity.

Another significant problem in impulse-noise exposure is that recovery from such exposures frequently does not occur in the orderly, predictable fashion usually observed with steady noise exposure (28). The result is that the length of time required for recovery cannot readily be predicted for impulse-noise exposures.

Finally, there is the extreme difficulty of measuring the important parameters of impulse-noise exposure (see section entitled "Considerations Underlying Noise Measurement Procedures," page 20). Because impulse noises are very short events characterized by rapid changes in pressure, highly specialized instrumentation is required to measure accurately the parameters required to assess hazard (22).

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[4] In MIL-STD-1474A, the number of categories was reduced to two. See section entitled "Major Changes Reflected in MIL-STD-1474A(MI)," page 27.

For these reasons, a somewhat different approach was taken in MIL-STD-1474(MI) in specifying design limits for systems involving impulse-noise exposure.

Unprotected Exposure

The maximum design limit for unprotected exposure to impulse noise is 140 dB peak pressure level. This limit derives from TSG's position, stated in TB MED 251 (11), that personnel exposed to impulse noises above 140 dB should always wear hearing protective devices.

TSG's position is, in turn, derived from two considerations. First, the CHABA Working Group 46 report (29) stated that there was evidence to indicate that exposure to impulse noise levels above 140 dB could cause hearing loss. Second, since weapon-produced impulse noise is such a significant problem in the Army, personnel should use hearing protection in every feasible situation when exposed to weapon noise. Conveniently, 140 dB peak level serves as an appropriate "break point," since virtually all Army weapons produce impulse-noise levels higher than 140 dB.

Protected Exposure

Design limits for protected exposure to impulse noise above 140 dB are specified in terms of the number of expected exposures per day <u>and</u> the type of hearing protective device(s) to be worn by exposed personnel. A two-way table [Table 6 in Section 5.4 of MIL-STD-1474(MI)[5]] provides three categories of number of exposures per day, and three categories of use of hearing protectors. Having selected the appropriate categories using this table, the corresponding design limits are shown in Figure 3 of Section 5.4[6] These limits are plotted in terms of peak pressure level in dB, and B-duration in milliseconds.

The protected impulse-noise design limits were derived by combining exposure limit recommendations from the CHABA Working Group 57 report (30) with the impulse-noise attenuation values empirically determined by Garinther and Hodge (21). The Working Group 57 report presented exposure limits (peak level vs. B-duration) intended to prevent excessive TTS in 95 percent of exposed persons. (Acceptable TTS was defined as 10 dB at or below 1000 Hz, 15 dB at 2000 Hz, and 20 dB at or above 3000 Hz.) The basic exposure limits for 100 impulses per day were supplemented by a correction factor for different numbers of impulses per day, which allowed a 5 dB increase in peak level for a 10-fold reduction in number of impulses, and vice versa.

Garinther and Hodge (21) determined the impulse-noise attenuation value of earplugs (specifically, the V-51R) as part of their comprehensive research project on rocket noise hazards. Their data indicated that well-fitted earplugs provided about 29 dB of attenuation; they further estimated that the use of earplugs and earmuffs together would provide an additional 5-6.5 dB of impulse-noise attenuation. So, these amounts of attenuation were added to the basic Working Group 57 criteria (30) to construct the limit curves included in MIL-STD-1474(MI).

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[5] Table 5 in MIL-STD-1474A(MI).

[6] Figure 5 in MIL-STD-1474A(MI).

It should be noted that no design limit is provided for an exposure condition of five impulses per day, with personnel wearing both earplugs and earmuffs. The reason is that, for B-durations typical of current Army weapons, the increase in allowable peak level would bring the exposure into the range where injury, other than to hearing, may occur (24). Gas-containing organs--the lungs, for example--are very susceptible to injury at high impulse-noise levels. Bowen, et al. (5), shows that minor lung hemorrhage begins to occur at about 7 PSI (187 dB) when the duration is 20 milliseconds and a reflecting surface is nearby.

Design Limits for Aural Non-Detectability

In many cases, it is imperative that the enemy not be able to detect military equipment aurally. Two approaches may be taken in determining the aural non-detectability distance of equipment: (1) a subjective method, in which personnel actually listen to the sound produced by the item (4); and (2) a computational method in which sound propagation and other assumptions are used to calculate the distance beyond which a sound will be inaudible.

Both methods present disadvantages. The subjective method is very expensive and time consuming; it is highly variable because of the normal variability of all subjective testing, as well as differences in weather and terrain between tests. The computational approach, likewise, has limitations; one of the more significant ones is the lack of complete data on ground-to-ground sound propagation.

The computational approach was the preferred choice for developing design limits of MIL-STD-1474(MI) because of the following advantages over the subjective approach: (1) it is much less expensive and time consuming; (2) there is no dependence on varying test site and weather; and (3) if properly conducted, the measurements required to establish conformance are repeatable at different test sites.

The computational method for determining aural non-detectability distance is elaborated in detail in Appendix E. Briefly, this method takes into account the presumed background noise level at the listener's location, the listener's hearing acuity, various factors affecting the detectability of sounds under field conditions and the transmission and absorption of sound in various octave bands as it travels from the source to the listener.

The octave band limits are presented in Section 5.2.1.1, Table 4 of MIL-STD-1474(MI)[7] for non-detectability distances ranging from 5 to 4000 meters. To simplify establishing conformance to these limits, the measurement of source noises is performed at much closer distances, ranging from 1-1/4 to 25 meters. Thus, the limits were calculated so that, for example, if the source is to be nondetectable at 300 meters, the stated octave band SPL limits must not be exceeded at a measurement distance of 10 meters.

Exterior Acceleration and Drive-By Noise

Transportation noise sources are increasing in number and level as our communities continue to increase in population density. The resulting increases in community annoyance brought about the passage of the Noise Control Act of 1972 (46). Although this act exempts "any military weapons or equipment which are designed for combat use," the intent of MIL-STD-1474(MI) is to provide procuring activities and designers with guidance so that non-exempt materiel may meet the forthcoming EPA requirements. These noise limits apply mainly to Army motor vehicles and to construction and materials-handling equipment.

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[7] Table 3 in MIL-STD-1474A(MI).

At the time this Standard was written (1971-1973), the major documents limiting exterior motor vehicle noise for community annoyance purposes were as listed in Table 9. The Department of Transportation (DOT) (18) and California (17) codes are certification requirements, as opposed to enforcement procedures. They apply to the sale of new motor vehicles within their respective regulatory jurisdictions. The Society of Automotive Engineers (SAE) documents (35, 37), on the other hand, are advisory only; their use is entirely voluntary.

TABLE 9

Exterior Noise Regulations and Their Limits

Document	Gross Weight (lbs)	Sound Level Limit [dB(A)]
Proposed DOT (18)	> 6000	86
	≤ 6000	84
California Code (17)	> 6000	86
	≤ 6000	84
SAE J366 (35)	> 6000	88
SAE J986 (37)	≤ 6000	86

The limiting noise levels selected for use in MIL-STD-1474(MI) were the lowest of those shown in Table 9 for the two weight categories. It should be noted, however, that both the DOT and California noise limits are programmed to decrease periodically, and the levels selected were those in effect at the time of issuance of the Standard. It is most likely that the EPA noise limits (whenever published) will follow a similar procedure; therefore, the noise limits of MIL-STD-1474(MI) for exterior noise will have to be revised downward at intervals.

For construction and materials-handling equipment, the limits and test procedures of SAE J88 (36) were selected as being the most appropriate.

Regarding test procedures for determining motor vehicle compliance, the concensus was that the SAE procedures would probably be adopted in the forthcoming EPA documents. Although the Army has some reservations about these procedures (e.g., load is not specified, nor is the type of terrain between the noise source and the microphone), they were adopted for use in MIL-STD-1474(MI).

CONSIDERATIONS UNDERLYING NOISE MEASUREMENT PROCEDURES

General Test Procedure Philosophy

The underlying philosophy behind the measurement procedures specified in MIL-STD-1474(MI) is that equipment should be tested under a single, constant operating condition whose noise output approximates typical operations.[8] Despite the paucity of data in this area, we believe this to be the most accurate and practical method of assessing equipment noise for the various purposes of the Standard. Ideally, it would be desireable to assess the noise under those conditions in which the equipment will actually be used in both training and combat; however, for acceptance purposes, this form of testing is impractical. In most cases it is not precisely known how the items will be used under various noise producing conditions. Also even if a representative mission profile were to be established, identical testing could not be performed

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[8] The foreword to MIL-STD-1474(MI) states in part: "Design standards . . .are intended to cover typical operational conditions." (Ref. 15, p. iii.)

by different agencies due to differences in terrain, road surface, grade and other variables. It would also be impractical in most cases to perform noise measurements for the length of time representative of a typical operating day(s).

For example, a single constant operating condition was determined for the M60A1 tank in a recent field study performed by HEL (20). During this study noise measurements were made in a tank during four typical operational days of platoon-size maneuvers. The average effective SPL was determined for this period and was compared to the SPL obtained when the vehicle moved at a constant speed along a smooth, level road in 5 mph increments up to 25 mph. The results (Fig. 3) indicated that the average SPL for an M60A1 tank during a typical operational day is approximated by constant operation at between 5 and 10 mph. These speeds may seem low, but it must be remembered that even in a road march, where the tanks are moving at a nearly constant speed, the march speed is usually 12 mph with a maximum of 15 mph for catch-up. In other maneuvers included in the study, the tanks rarely exceeded 10 mph. It would appear, then, that an "equivalent constant noise condition" for this item of equipment would be about one-third of its maximum speed when moving on a level, hard surface.

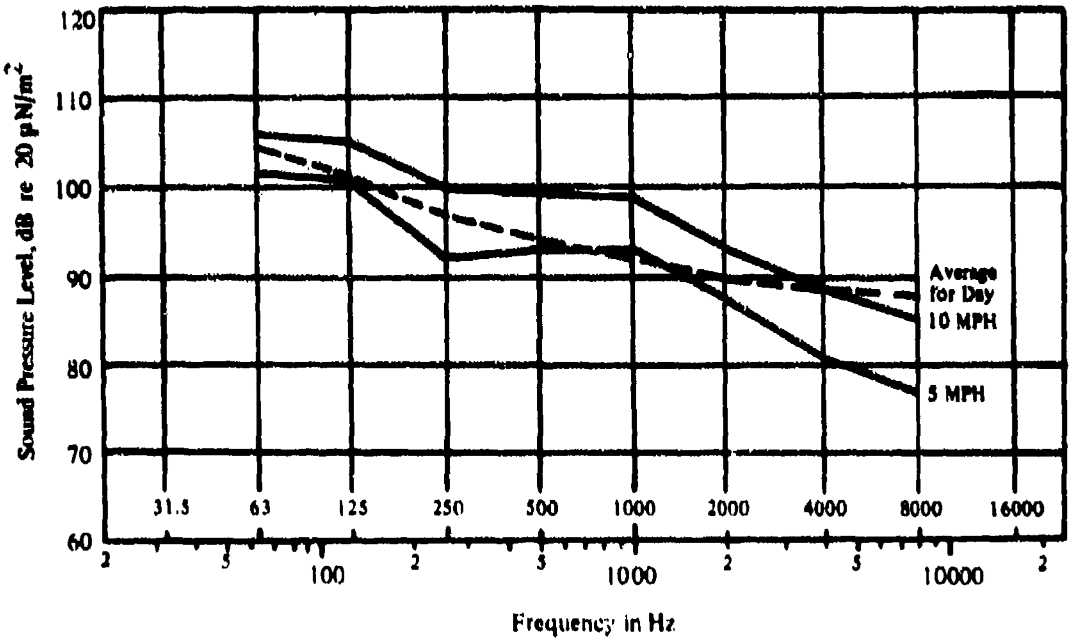

Figure 3. Octave band pressure levels in the turret of the M60A1 tank at 5 and 10 MPH compared to the average level for a typical operational day. (From Ref. 30.)

Until additional data is developed about eqivalent constant noise conditions for various items, particularly vehicles, the Standard requires their noise to be measured at two-thirds of maximum rated or governed engine speed in that gear producing the highest SPL. The concensus was that this procedure provided that single test condition most closely representing a typical operational day for most Army vehicles. In addition, the Standard stipulates that vehicles carry two-thirds of maximum payload, and travel on a smooth, level road.

It was determined, however, to be inappropriate for certain types of equipment to be tested at two-thirds speed with two-thirds load, particularly earth-moving and construction equipment. For these items, the procuring activity is permitted to specify a repeatable, steady operating condition which produces about the same noise output as experienced during typical duty cycles. At a later date is is hoped that sufficient data will be available to specify in the Standard equivalent constant noise conditions for these types of materiel.

The measurement locations for compliance with MIL-STD-1474(MI) are those locations where operators or other personnel must be located for the item to accomplish its primary mission. Maintenance areas and specialized instructor locations are not included. For example, the possible hearing hazard which may be encountered under the hood of a truck in a maintenance shop should not be considered in testing the truck for acceptance; that problem should be covered under the maintenance shop's hearing conservation program.

Instrumentation Procedures

The instrumentation procedures presented in this Standard reflect the most current noise measurement techniques available. The techniques were formulated to be restrictive enough to provide consistent, repeatable data from different agencies, while providing sufficient latitude to permit the use of various manufacturers' instrumentation.

Steady-State Noise

Personnel Limits and Locations

When measuring noise, the location of equipment operators and instrumentation technicians must always be considered. Most damage risk criteria and intelligibility guidelines are based on data taken with no operator present; thus it is important when collecting noise data that the operator <u>not</u> be in his normal position unless his presence is required to operate the equipment. In many cases, his presence could cause artifacts due to noise reflection from, and/or shadowing by, his head and body.

When the operator must be present, the Standard stipulates that measurements be made 6 inches to the right of his right ear. Consideration was given to the possibility of taking data to the side of both ears, or using the left ear, but it was decided that the right-ear measurement would be the most representative of the no-operator condition. An additional consideration was that for vehicular noise this position is usually sheltered from possible wind interference. If a reflective surface (such as a wall) is within 12 inches of the right ear, the Standard requires the microphone to be positioned equidistant from his ear and that surface. Care must be taken under these circumstances to ascertain that the microphone location is representative of the operator's head position, that it is not measuring a standing wave, and that the wall itself is not the major noise source. In the latter case, the SPL at the operator's head location might be significantly lower.

Measurements made in enclosures, such as small shelters and personnel carriers, are to be made with as few people as possible in the area; usually two are sufficient. While several persons may usually be present in such enclosures during normal operations (in which case the noise level will be lowered due to absorption by their bodies), these personnel limits were imposed to specify a standardized technique, and to ensure that the noise measurements are not made under the ideal, or quietest, conditions.

The acoustical technician must always be careful not to stand between the microphone and a major noise source. Also, he must take care that his body not act as a reflecting surface, thereby increasing the measured SPL. Thus, he should stand to the side of a line extending through the noise source and the microphone. A remote microphone mounted on a tripod should be used whenever possible to obviate these problems.

Background Noise

Accuracy requires that the background noise be at least 10 dB below the noise level being measured, in each octave band. Even with this 10 dB difference, the background noise will add about 0.4 dB to the measured SPL. The ambient noise corrections given in Table 10 may be used to compensate for the effect of background noise.

TABLE 10

Ambient Noise Corrections (dB)

Difference Between Total Measured SPL and Measured SPL of Ambient Noise Only	Correction to be Subtracted from Total Measured SPL to Obtain SPL of Noise Source Only
4	2.2
5	1.7
6	1.3
7	1.0
8	.8
9	.6
10	.4
11	.3
12	.3
13	.2
14	.2
15	.1

From Ref. 2.

Microphone Orientation

At frequencies above 1 kHz, differences of several dB may occur due to microphone orientation. Most American microphones have their optimum response at random incidence, which is similar to that obtained at grazing (90°) incidence. However, some European microphones (such as the 1-inch Bruel and Kjaer 4131) provide optimum response at normal (0°) incidence. When making measurements in an enclosed area such as a shelter, most incident noise would strike the microphone in a horizontal direction, rather than from above or below it. Since reflected sound would strike the microphone from all directions, optimum data will be obtained by positioning a microphone, having its flattest response at grazing or random incidence, vertically with the sensitive element up. If a grazing-incidence microphone is not available, a normal-incidence microphone may be used provided that a random-incidence corrector is used. Any other type of microphone, or other orientation, may produce data differing from the standardized method required by MIL-STD-1474(MI).

When making exterior noise measurements of a single stationary source, the microphone must be oriented in a manner which produces the most uniform frequency response. When measuring the noise of a moving source, in which data must be obtained continuously along its trajectory, a grazing-incidence microphone should be oriented so that the plane of the diaphragm (or sensitive element) passes through the line of travel of the source. Only in this way, will the noise strike the microphone at the same incidence angle at all points along its line of travel.

Impulse Noise

The assessment of impulse noise for compliance with MIL-STD-1474(MI) requires the measurement of the peak pressure level and the envelope duration (B-duration) of the pressure wave.

Unwanted Reflections

Accurate measurement of duration requires that only unavoidable reflected sound and shock waves reach the measurement location during the period between the onset of the impulse and the end of the B-duration. Ground reflection is, of course, unavoidable and is typical of most impulse noises. Sound and shock waves of the types usually encountered travel at a nominal velocity of about 1 foot per millisecond. Therefore, to obtain a measurement interval of 60 milliseconds free of unwanted reflections, it would be necessary for reflecting surfaces (other than the ground) to be located at least 30 feet from the noise source. For impulse noises having B-durations longer than 60 milliseconds (a rarity in open areas), it would be necessary to position reflecting surfaces more than 30 feet away; if, however, the reflected peak level is more than 25 dB lower than the peak level of the noise source, this increase in distance would not be necessary.

Where it is necessary to place an instrumentation trailer or van near the noise source, reflections can be minimized by orienting them such that the direct sound or shock wave strikes a corner of the trailer, thus causing the reflected shock waves to propagate away from the transducer.

Transducer Location

Following considerable discussion, it was decided to standardize on a measurement position for impulse noise, which is midway between the right and left ear position of the operator or shooter. (The operator will, of course, be absent when the measurements are being taken.) The peak pressure level difference between the two ear positions is usually less than 1.5 dB, so this measurement location represents an average exposure. Also, for systems where one ear is very close to the weapon (e.g., rocket launchers, and rifles), this makes it easier to position the transducer because its location will be at least a few inches away from the weapon.

In addition to measurements taken at the operator position, it is recommended that a measurement also be made at a position two meters to the side (90°) of the major noise source (muzzle or breech, as the case may be). The purpose of this measurement is to provide data at a standardized location which is the same for weapons of a given type, as opposed to the operator's location, which changes from weapon to weapon. This type of data is valuable when comparing various weapons for design purposes. The 2-meter, 90° location also provides information for an assessment of the hazard presented to personnel other than the operator (such as crew members or coaches) who might be close to the weapon.

Transducer Characteristics and Orientation

The principal transducer considerations in measuring impulse noise are its rise-time characteristics and its orientation with respect to the shock wave. Garinther and Moreland (18) have shown that at normal (0°) transducer incidence the peak pressure level measured by various transducers may differ by as much as 3-10 dB. Rice and Coles (32) found differences on the order of 2-6 dB. On the other hand, peak pressure levels from different transducers oriented at grazing incidence (90°) should theoretically be, and were in fact found to be in good agreement, provided the rise-time characteristics and damping characteristics were appropriate (7). For these reasons, it has been agreed that for impulse-noise measurements the transducer should be oriented at an angle of 90° between the longitudinal axis of the transducer and the direction of travel of the shock wave.

A transducer's rise-time capability becomes increasingly important as the duration decreases. For transients having a nearly linear change of the first rise and fall in pressure (A-duration), such as produced by rifles and howitzers , there is a simple relationship (Fig. 4) between the percent error and both the A-duration of the impulse and the rise-time capability of the transducer. This relationship expresses itself as:

$$T_r = E \times T_d \qquad (3)$$

where T_r is the rise-time capability of the transducer, E is the permissible error, and T_d is the A-duration of the transient.

Since the rise-time characteristics of a transducer should be such that measurement error will not exceed 0.5 dB (or about 5 percent), it follows from Equation 3 that:

$$T_r = .05\,T_d \qquad (4)$$

or, that the rise-time capability should not exceed 1/20 of the A-duration. Rise-time capability is dependent on transit time of the shock wave across the sensing element (i.e., the diameter of the sensing element), the damping characteristics of the transducer, and its frequency response. For weapons such as small arms, the required rise-time capability is in the order of 10 microseconds when calculated from Equation 4.

The rise-time capability of some transducers varies with pressure, so it is important that this determination be made at the pressure being measured. Normally this information can be obtained by observing the rise time actually measured for a weapon since the impulse arriving at operator locations close to weapons is usually a shock wave having a rise time of less than 1 microsecond. Rise-time capability can also be determined by means of a shock tube which produces a step-function or discontinuity in pressure. The pressure produced by a shock tube may be calculated very accurately by means of the Rankine-Hugoniot equation:

$$P_s = 7/6\,P_0\,(m^2 - 1) \qquad (5)$$

where: P_s is the shock wave overpressure, in PSI; P_0 is the ambient pressure, in PSI; m is the Mach number (or, v/c); v is the velocity of the shock wave, in feet per second; and c is the velocity of sound, in feet per second. When a transducer measures the shock tube pressure wave, the pressure-time history is an accurate index of the transducer's rise-time capability for a given pressure, at a given angle of incidence. Moreover, the shock tube produces an accurate, preselected pressure, which is a useful reference for two purposes: (1) validating the manufacturer's sensitivity specification, and (2) verifying other calibration methods, such as a pistonphone. The transducer's ringing and overshoot characteristics may also be evaluated using the shock tube approach.

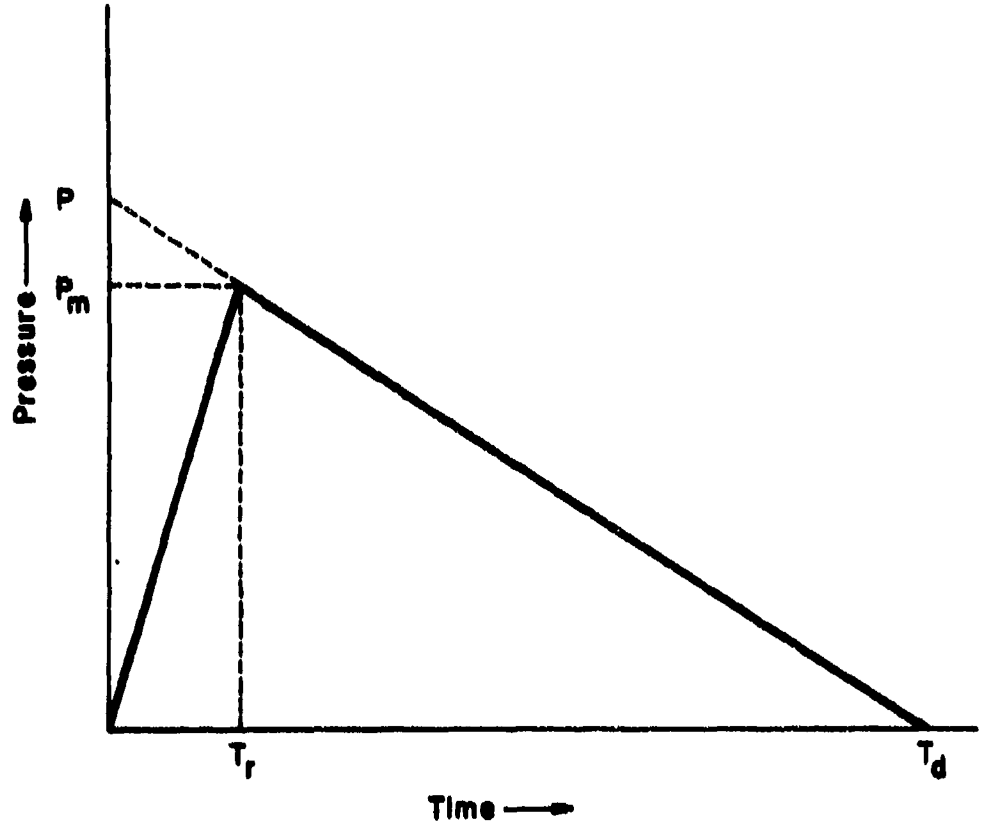

Figure 4. Determination of error introduced as a result of inadequate rise-time capability when measuring a short acoustical transient having "instantaneous" rise time. T_r is the measured rise time; T_d is the A-duration; P_m is the measured peak pressure; P is the actual peak pressure. (From Ref. 22.)

Readout Instruments

Two approaches can be used for recording and measuring impulse noise pressure-time histories: (1) photographing the trace obtained on a cathode-ray oscilloscope; or (2) obtaining a trace from a strip-chart recorder. Strip-chart records have galvanometers whose frequency response does not meet the 40 kHz requirement specified in MIL-STD-1474(MI), so it is necessary to tape-record the impulse at a speed sufficient to achieve a DC to 40 kHz response, and then play it back into the strip-chart recorder at a low speed. For example, if 5 kHz galvanometers are used and the impulse noise was recorded at 60 inches per second, a response of 40 kHz would be obtained at a playback speed of 7-1/2 inches per second.

Remember that magnetic recording of an impulse noise requires the use of an FM recorder with a frequency response to at least 40 kHz. Direct (AM) tape recorders produce phase shift between time and frequency which completely changes the characteristic waveshape on playback. Also, a response limited to less than 40 kHz causes some of the short-duration pulses or spikes to be attenuated on weapons such as rifles and rocket launchers.

Estimating Peak Pressure Level

When measuring impulse noise it is often desirable to estimate the pressure produced by a weapon prior to the first firing. The following two equations may prove helpful in making such determinations.

Equation 6 (49) may be used to determine the free field pressure to the side (90°) of a closed breech weapon without a muzzle brake:

$$P = \frac{4.4 \times 10^{-2} W}{\ell \, L_{\perp}^{3/2} C^{1/2}} \tag{6}$$

where: P is the pressure, in PSI; C is the caliber of the weapon, in inches; ℓ is the barrel length, in inches; W is the powder energy minus kinetic energy of the projectile, in inch-pounds; and $L_{\perp}$ is the distance perpendicular to the line of fire, in inches.

Equation 7 (50) may be used to determine the pressure of a supersonic projectile[9]:

$$P = \frac{0.53 P_0 d(m^2 - 1)^{1/8}}{y^{3/4} L^{1/4}} \tag{7}$$

where P_0 equals 14.7 PSI; m is the projectile Mach number; d is the projectile diameter, in inches; y is the miss distance, in inches; and L is the projectile length, in inches.

MAJOR CHANGES REFLECTED IN MIL-STD-1474A(MI)

As discussed in the section entitled "Historical Background of Army Noise Standards," (page 3), the A-revision of the Standard was based on a year of use by Army design and procuring activities, plus six months of informal discussion of problems that arose, followed by the usual formal coordination and a resolution meeting. There were surprisingly few requests for major changes in the Standard. Those which were finally accepted by consensus of the review activities are briefly described below.

Addition of dB(A) Criteria for Steady-State Noise

In addition to the octave band SPL limits for the six design categories, MIL-STD-1474A(MI) provides dB(A) limits as well. Moreover, equipment may now be accepted on the basis of either octave band SPLs or A-weighted SPLs. Primarily, this change reflects the increasing acceptance of A-weighted SPL as a measure of noise where its effects on man are paramount.

Deletion of Commercial Frequency Limits for Steady-State Noise

Table 3 in MIL-STD-1474(MI) presented steady-state noise limits as octave band levels for the older, commercial frequency bands. This table was included because it was assumed that it would facilitate the comparison of data on equipment presently in inventory with the provisions of the Standard (which, of course, are given for the newer, preferred frequencies). This table proved to be unnecessary, so it was deleted from MIL-STD-1474A(MI), and the appropriate ANSI standard was referenced for conversion to the commercial frequencies.

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[9] Note: MIL-STD-1474(MI) does not specify a limit on the impulse noise produced by projectiles. We usually let the enemy worry about that!

Changes in Communication Criteria

Reduction in Number of Design Categories

Three design categories (E, F and G) were provided in MIL-STD-1474(MI) for various types of voice communication requirements. In the revision this number was reduced to two, and the descriptive bases for category selection were simplified. The communication categories are now based entirely on telephone use and direct (unaided) voice communication. These changes were made to bring the provisions of the revised Standard into consonance with the forthcoming revision of MIL-STD-1472.

Substitution of dB(A) and PSIL-4 Criteria for Octave Band Limits

As noted above, dB(A) criteria were included in the revised Standard for all steady-state noise categories. For the two communication categories (only), the corresponding octave band limits were deleted, and alternate PSIL-4 (Preferred Speech Interference Level) limits were provided for situations where the dB(A) limits cannot be met. PSIL-4 is the average of the octave band pressure levels at 500, 1000, 2000 and 4000 Hz. These changes were made to bring the revision into consonance with MIL-STD-1472.

Provision for Duty Cycle Testing

One commodity command in particular found that is was inappropriate to test much of its equipment under a constant operating condition, due to the large fluctuations in noise level they observed. For such situations the revised Standard allows the noise to be measured for at least an hour and permits the computation of an equivalent continuous noise level (L_{eq}*). Note that the computation is quite different from that used for the currently popular L_{eq}, because L_{eq} is based on a 3 dB trading relation between time and intensity, whereas L_{eq}* is based on a 5 dB trading relation as specified in TB MED 251 (11).

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APPENDIX A

DEPARTMENT OF THE ARMY
HEADQUARTERS UNITED STATES ARMY MATERIEL COMMAND
WASHINGTON, D.C. 20315

AMCDL 1 November 1972

SUBJECT: Standard for Noise Levels

SEE DISTRIBUTION

1. Research into the problem of premature hearing loss by Army personnel indicates that this is the most common disability in the Army. A concentrated effort must be made to alleviate this problem.

2. Department of Army Technical Bulletin, TB MED 251, Noise and Conservation of Hearing, sets forth criteria and guidelines for hearing conservation programs.

3. A new revision to the Human Engineering Laboratory noise level standard is being distributed. This revision takes cognisance of the criteria for hearing conservation set forth in TB MED 251, and incorporates into one document the requirements for improved speech communication, decrease of aural detection by the enemy, as well as the noise limits established by TB MED 251 and proposed Federal regulations. This latest revision, titled "HEL Standard S-163C, Materiel Design Standard for Noise Levels of Army Materiel Command Equipment," September 1972, will be used by all elements of this command as a guide, until the mandatory military (Army) standard is published.

4. Recently, there has been considerable informal coordination both within AMC and among AMC, TSG, USACDC, and DA in the preparation of HEL S-163C. Since the military standard will be based on HEL S-163C, formal coordination of the military standard, at least within AMC, should be accomplished expeditiously by all concerned. Target date for publication of the military standard is 3rd Qtr FY 1973.

FOR THE COMMANDER:

CHARLES T. HORNER, JR.
Major General, USA
Chief of Staff

DISTRIBUTION:
A & B

APPENDIX B

MIL-STD-1474 RESOLUTION MEETING PARTICIPANTS
(7-9 February 1973 at USAHEL)

Chairman and Acting Project Officer

Mr. Gerald Chaikin	US Army Missile Command

Major Command Spokesmen

Dr. R. H. Duguid	Office of The Surgeon General
Mr. Patrick E. Brett	Office of the Chief of Engineers
MAJ A. R. Reinke	Combat Developments Command
Mr. John R. Erickson	Army Materiel Command (designate)

Commodity Command Spokesmen

Mr. George L. Bonvallet	Tank-Automotive Command
Mr. Gerald Chaikin	Missile Command
Mr. Georges R. Garinther	Human Engineering Laboratory
Mr. Paul Hopler	Mobility Equipment R&D Center
Mr. Roger Lerwill	Test & Evaluation Command
Mr. Stephen Moreland	Aviation Systems Command
Mr. John Rakowski	Electronics Command
Mr. Don Voracek	Weapons Command

Technical Consultants and Observers

LTC F. A. Copeland	Combat Developments Command
Mr. Dean B. Blazie	Human Engineering Laboratory
Mr. Paul A. Fair	Human Engineering Laboratory
Dr. David C. Hodge	Human Engineering Laboratory
CPT Charles E. Perez	Human Engineering Laboratory
Mr. William H. Diegel	Aberdeen Proving Ground
Mr. William J. Haslem	Tank-Automotive Command
Mr. Arthur C. Kirkland	Tank-Automotive Command
Mr. Leonard S. Moore	Tank-Automotive Command
Mr. Roger Heymann	Environmental Hygiene Agency
Mr. E. C. Manning	Office of the Chief of Engineers
Mr. Calvin G. Moler	Test & Evaluation Command
Mr. Samuel Wehr	Mobility Equipment R&D Center

Recording Secretary

Mrs. Betty Frazier	Human Engineering Laboratory

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APPENDIX C

MEMORANDUM FOR RECORD

SUBJECT: Proposed MIL-STD-XXXX, Noise Limits for Army Materiel

1. A comment resolution meeting was held, 7-9 February 1973, at the US Army Human Engineering Laboratory, Aberdeen Proving Ground, Maryland, to resolve comments submitted on subject MIL-STD. Participants included representatives of organizations as indicated by Incl 1.

2. All essential comments were resolved.

3. Changes to MIL-STD-XXXX proposed by The Office of the Surgeon General (OTSG), DA (per Para 2 of Incl 2 to 1st Ind to letter, AMSMI-RCS, USAMICOM, 11 Jan 73, subject: MIL-STD-XXXX (Army) (Proposed) Noise Limits for Army Materiel, DOD Project MISC-A867), are withdrawn subject to the following actions to be taken:

a. USAAVSCOM, as the Army custodian for MIL-A-8806A, will establish an Army working group to revise said document. The position established by this group will be the Army position presented to the Air Crew Station Standardization Panel (ASSP) for adoption by all three services. (A tri-service adhoc working group of the ASSP has been established to revise MIL-A-8806A and is scheduled to convene during the fourth quarter of FY 73.)

b. USAAVSCOM officially request through standardization channels to the preparing activity (NASC) that a project be initiated to revise and update MIL-A-8806A with reference to OTSG comments noted above, and that the preparing activity notify USAAVSCOM of the date of initiation of the project. (USAAVSCOM will then notify OTSG of this date.)

c. Participation in the above will include the TSG, DA, such other representatives within the Army Medical Department as TSG, DA, may designate, the USAHEL, and other appropriate activities to be determined.

4. It is recommended that:

a. Proposed MIL-STD-XXXX be promulgated, with changes, as agreed during the comment resolution meeting.

b. A project be initiated, as soon as possible, to revise MIL-STD-XXXX for updating requirements and to reconsider withdrawn comments.

c. The "A" revision, when approved, be submitted for consideration as a fully-coordinated MIL-STD.

d. The industry group to whom solicitation for comment on proposed Revision A be broadened.

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APPENDIX D

MIL-STD-1474A RESOLUTION MEETING PARTICIPANTS
(10-11 December 1974 at USAHEL)

Chairman and Acting Project Officer

Mr. Gerald Chaikin	US Army Missile Command

Major Command Spokesmen

Mr. Craig Schilder	Department of the Army
COL John E. Ward	Office of The Surgeon General
MAJ R. M. Clearwater	Troop Support Command
Mr. Charles Jordan	Army Materiel Command

Commodity Command Spokesmen

LTC J. H. Fahrni	Aviations Systems Command
Mr. S. M. Sorin	Armaments Command
Mr. Samuel E. Wehr	Mobility Equipment R&D Center
Mr. Joseph P. Delaney	Test & Evaluation Command
Mr. Georges R. Garinther	Human Engineering Laboratory
Mr. George L. Bonvallet	Tank-Automotive Command
Mr. Gerald Chaikin	Missile Command

Technical Consultants and Observers

Mr. John H. Dye	Aberdeen Proving Ground
Mr. William H. Diegel	Aberdeen Proving Ground
Mr. F. Z. Sachs	Environmental Hygiene Agency
CPT Thomas L. Gooding	Environmental Hygiene Agency
Mr. Roger Heymann	Environmental Hygiene Agency
Mr. Paul Hopler	Mobility Equipment R&D Center
Mr. Charles W. Houff	Human Engineering Laboratory
Dr. David C. Hodge	Human Engineering Laboratory

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APPENDIX E

COMPUTATIONAL METHOD OF DETERMINING AURAL NON-DETECTABILITY LIMITS

To compute those sound levels which will be non-detectable at various distances, it is necessary to consider a number of factors such as the following:

1. Frequency Analysis. The propagation of sound through air, and the detectability of sound by man, vary with frequency, so computations must be conducted by frequency bands. An octave band analysis was selected for use in this method because it provides sufficient frequency discrimination and because octave band analyzers are readily available.

2. Signal-to-Noise Ratio. We must decide what assumptions to make about the ratio between the background noise level and the level of the source noise. Two factors may be considered in making this decision: the presence of pure tones in the source noise, and intermittency of the source noise. It was decided, however, not to use either a pure tone correction or an intermittency correction for these calculations. In most cases it is difficult to determine from an octave band analysis whether a pure tone is present; to have required a one-third-octave or narrower analysis would have unnecessarily complicated the Standard. With respect to intermittency, it was assumed that under the variable noise conditions encountered in combat, changes in sound level of less than 2-3 dB would not be detected. Also, some sound sources, such as generators and air conditioners, are continuous; the listener is therefore not given the advantage of detecting an intermittent change in level. For these reasons, non-detectability was assumed to hold when the sound, traveling away from its source, decreased to a level equal to or below the background noise in each octave band.

3. Background Noise Level at Listener's Location. In developing a representative background noise level, the levels in five different areas were considered:

a. US suburbs at 2200 hours (no expressways, railroads, or industrial noises present).

b. Rural France (same conditions as above).

c. Aberdeen Proving Ground, at 0400 hours.

d. Jungle, with no animal or insect noise (average of the Madden and Las Cruces jungles).

e. Same as above, with animal and insect noise.

These levels, shown in Figure 1E, were used to develop a lower composite limit which would be below most background levels likely to be encountered in combat, which was then normalized to a level of 20 dB in each octave band for the range of 63-8000 Hz.

4. Listeners' Hearing Acuity. The sensitivity of hearing selected was that reported by Robinson and Whittle (33) for average hearing of young, normal adults listening with both ears in a free field.

Figure 2E shows a composite of the normalized background noise level and the average hearing level. Based on the preceeding discussion (3 and 4, above) non-detectability exists when the level of the sound to be detected, at the listener's location, is equal to or below the higher of both the background noise level and the average hearing level, in each octave band.

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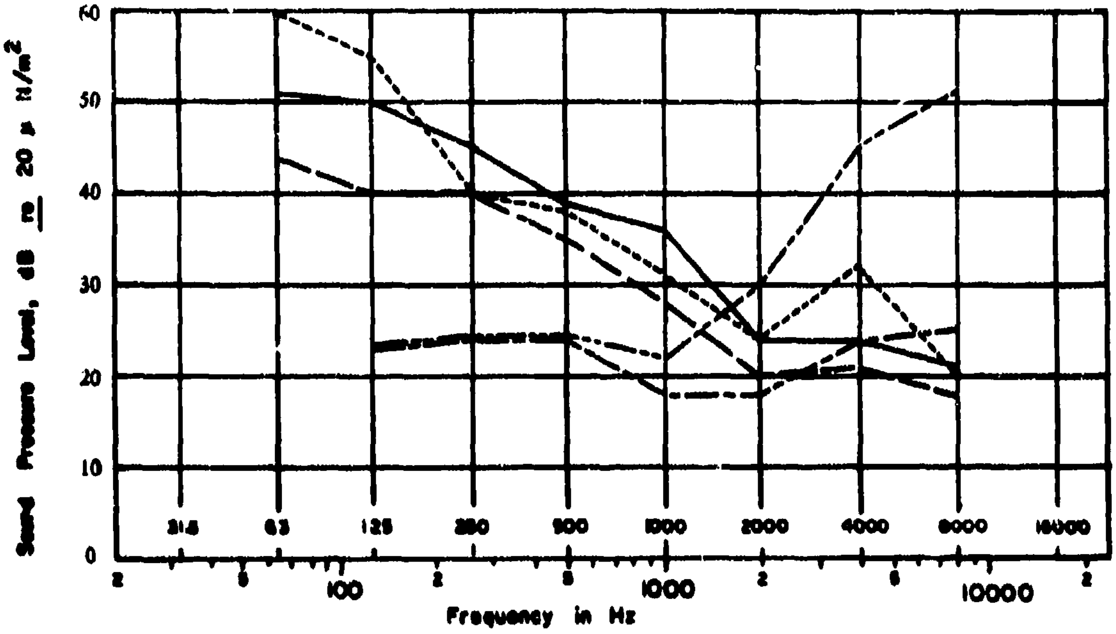

——————— U. S. suburbs (no expressways, railroads, or industrial noises are present) at 2200 hours.

— — — — Rural France (same conditions as above).

--------- Aberdeen Proving Ground 3-Mile Straightaway at 0400 hours.

——-——-—— Jungle noise with no animal or insect noise (average of the Madden and Las Cruces jungles).

——··——··—— Same as above with animal and insect noise.

Figure 1E. Octave band-pressure levels of typical background noise in various areas.

NOTE: These data have been on file, and in use, in our laboratory for a number of years; unfortunately, however, the original source of the data has been lost.

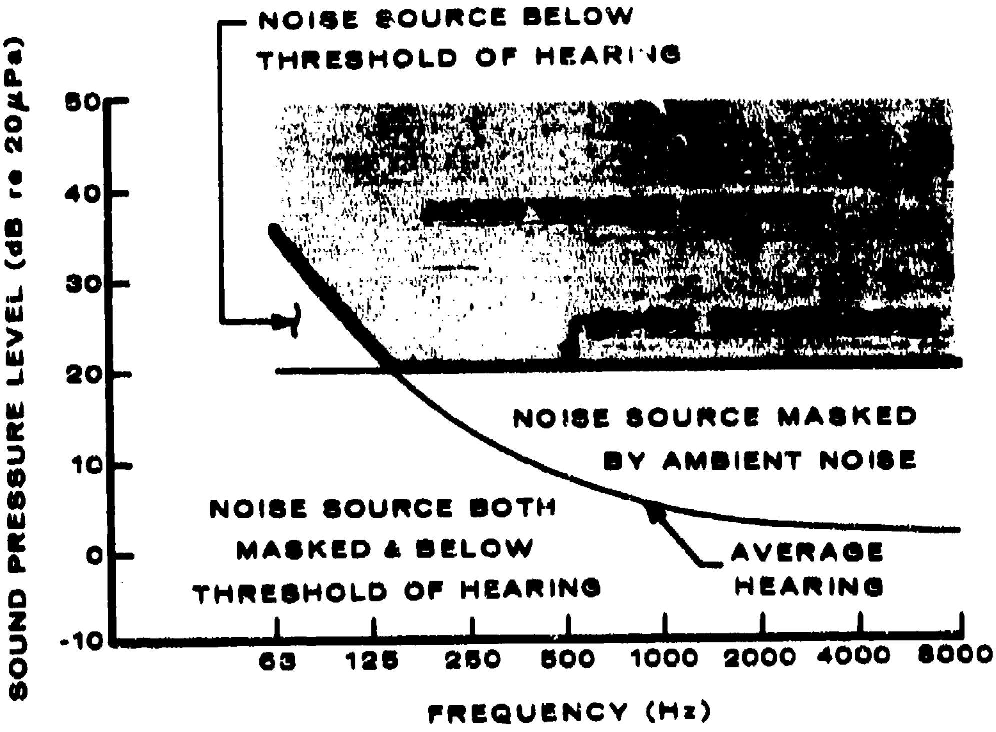

Figure 2E. Effect of a quiet environment and threshold of hearing upon the aural detectability of a noise source. (From Ref. 16.)

5. Measurement Location for Determining Compliance with the Standard. It would be difficult, if not impossible, to measure source noise for compliance at the non-detectability distance, which may be as much as four kilometers. The signal of interest will usually be below the background noise level; also it would be difficult to find a test site of this size which would be flat and have uniform ground cover. To avoid these problems, measurement locations relatively close to the test item are specified, and the design limits at these locations were calculated so that, based on sound propagation to the non-detectability distance, the item will not be detectable if these limits are met. The measurement distances were selected by taking two factors into consideration:

a. The measurement must be made far enough from the source to be in the free-field portion of the far field, i.e., where the SPL decreases 6 dB for each doubling of distance. This region normally extends no closer than 3-5 times the major dimension of the noise source.

b. Measurements must also be made at a point where the SPL is high enough in each octave band to be 10 dB above the ambient noise level of most test sites.

6. Sound Attenuation with Distance. The attenuation of sound from the measurement location to the desired non-detectability distance must be computed. This computation is based mainly on the following:

a. Spherical Divergence. In an ideal, loss-free atmosphere, sound pressure decreases inversely with distance in the far field. SPL decreases 6 dB for each doubling of distance (or, 20 dB for each 10-fold increase in distance).

b. Molecular Absorption. Excess attenuation due to atmospheric conditions causes attenuation beyond that resulting from spherical divergence. In this computation, the only excess attenuation considered was that caused by the molecular relaxation behavior of the oxygen molecules in air. This molecular absorption depends on temperature, humidity and frequency. The molecular absorption values used to determine the non-detectability levels are those given in SAE ARP 866 (38) for a temperature of 70° F., and a relative humidity of 70%, as shown in Table 1E.

TABLE 1E

Molecular Absorption at 70°F and 70% Relative Humidity

Frequency (Hz)	63	125	250	500	1000	2000	4000	8000
Attenuation (dB/1000m)	0	0	0	2	5	11	25.5	39

From Ref. 34.

When the SPL at the non-detectability distance has been calculated, the SPL at the measurement location may be calculated from the following equation:

$$L_1 = L_2 + 20 \log \frac{r_2}{r_1} + Ae \qquad (8)$$

where: L_1 is the SPL at the measurement location, in dB; L_2 is the SPL at the non-detectability distance, in dB; r_1 and r_2 are the distances from the noise source to the measurement location, and to the non-detectability distance, respectively, in meters; and Ae is the excess attenuation due to molecular absorption for the distance $r_2 - r_1$, in dB.

For example, in calculating the band pressure level to be measured at 25 meters and 2000 Hz, for a non-detectability distance of 2000 meters, where L_2 equals 20 dB, equation 8 produces:

$$L_1 = 20 + 20 \log \frac{2000}{25} + 1.975(11) \approx 80 \text{ dB}.$$

The procedure outlined above was used to calculate the limiting octave band levels for aural non-detectability given in Table 4 of MIL-STD-1474(MI).[1] For non-detectability to be achieved at the desired distance, the applicable octave band pressure levels must not be exceeded in any band at the measurement distance. In using these limits, remember that no single noise limit will provide for non-detectability under all possible conditions of terrain, weather and listening. These limits are for non-detectability under commonly found, favorable sound propagation conditions. They will produce an actual detection distance which may occasionally be greater than, but more often will be smaller than, the nominal non-detectability distance of the Standard.

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[1] Table 3 in MIL-STD-1474A(MI).