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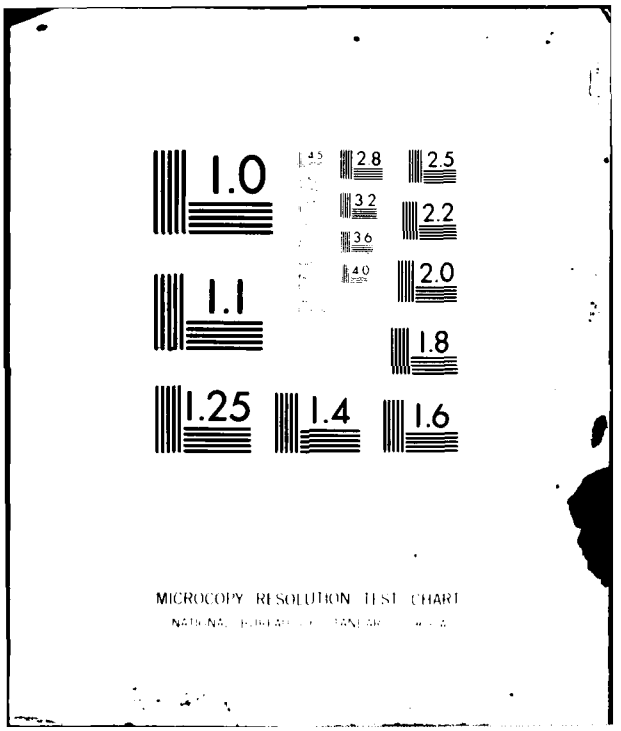
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A design standard for interior noise of helicopters has been prepared to provide the developer and user with realistic noise limits which consider hearing damage risk, speech intelligibility, mission profile, state-of-the-art in noise reduction, and helicopter weight. The levels selected meet the current hearing conservation limits of the Department of Defense and permit electrically aided sentence intelligibility of 98%. Helicopters below 20,000 pounds are treated separately from those above because of the strong positive relation between internal noise and vehicle gross weight.

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This standard defines the locations and flight conditions under which noise measurements shall be made for compliance. It also specifies the types of instrumentation and the test procedures to be used to collect interior noise level data. This degree of specificity in the instrumentation and measurements area is intended to insure that data collected by different development and test agencies will be both accurate and consistent.

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THE BACKGROUND AND BASES FOR THE PROPOSED MILITARY STANDARD ON ACOUSTICAL NOISE LIMITS IN HELICOPTERS

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March 1981

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The Background and Bases for the Proposed Military Standard on Acoustical Noise Limits in Helicopters

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Summary

A design standard for interior noise of helicopters has been prepared to provide the developer and user with realistic noise limits which consider hearing damage risk, speech intelligibility, mission profile, state-of-the-art in noise reduction, and helicopter weight. The levels selected meet the current hearing conservation limits of the Department of Defense and permit electrically aided sentence intelligibility of 98%. Helicopters below 20,000 pounds are treated separately from those above because of the strong positive relation between internal noise and vehicle gross weight.

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INTRODUCTION

Helicopter noise has been a problem since the helicopter's inception into military aviation in the late 1940's. As with other types of combat vehicles, excessive noise in helicopters has a variety of unpleasant or hazardous consequences, including communication interference and temporary or permanent hearing loss.

Excessive interior noise in helicopters prevents adequate person-to-person and electrically-aided speech communication. Surveys have indicated that in most military helicopters the degree of electrically-aided speech intelligibility is below that required by MIL-STD-1472B (1). This causes problems in command and control, reduces the effectiveness and response speed of air crews and, in some situations, can actually cause casualties due to misunderstood instructions.

Person-to-person communication is also often seriously degraded. In troop-carrying helicopters, a squad leader may only be able to give instructions to his men by shouting.

Noise-induced hearing loss also affects command and control. Temporary losses can persist long after leaving a vehicle, and this may interfere with the reception of spoken or whispered commands by troops that have been airlifted to a combat zone. Repeated exposure to excessive noise causes permanent hearing losses, the consequences of which are well known.

Until now the Army has not had a separate design standard for the noise of helicopters. Instead, as aircraft, helicopters were supposedly covered by MIL-A-8806A, "Acoustical Noise Level in Aircraft" (2) despite the fact that MIL-A-8806A was based on fixed-wing aircraft design, testing mission profiles, power requirements, etc. (Another drawback of MIL-A-8806A was its use of antiquated criteria for hazardous noise exposure.)

In 1972, when the first version of MIL-STD-1474 (3) was being prepared, the US Army Surgeon General attempted to include helicopters under the standard (which, of course, covers all other Army materiel). However, this was met with considerable resistance from the military aircraft community, and The Surgeon General was persuaded to allow the exclusion of helicopters from the provisions of MIL-STD-1474 on the condition that an effort be undertaken to develop a separate noise standard for Army helicopters. After several false starts a US Army Working Group on Helicopter Noise was formed, chaired by Mr. Steve Moreland of the U.S Army Aviation Research and Development Command. Organizations that were represented on the Working Group included: The Surgeon General, Training and Doctrine Command, Human Engineering Laboratory, Environmental Hygiene Agency, Avionics R&D Activity, Applied Technology Laboratory, and representatives of several major U.S. helicopter manufacturers.

CONSIDERATIONS UNDERLYING NOISE LIMITS

The following considerations were addressed during the development of this standard:

1. Potential hearing hazard to both the crew and passengers.
2. Speech intelligibility, both direct and electrically-aided.

3. Attenuation provided by the crew helmet, and hearing protectors which would be worn by passengers.

4. Potential noise exposure to unprotected passengers.

5. State-of-the-art of noise reduction in helicopters.

6. Typical mission profiles of various helicopters in peacetime and in wartime.

7. Weight penalty of adding noise reduction material.

As a preliminary step it was decided to plot the range of octave band levels encountered in various helicopters (4). Figure 1 shows this range along with the current limits of MIL-A-8806A. Also shown for comparative purposes are the octave band levels of a current state-of-the-art helicopter---the Blackhawk. As we shall see later in this paper the limits of MIL-A-8806A were unnecessarily restrictive in the 31.5-125 Hz and the 4000-8000 Hz bands, and too lenient from 250-2000 Hz.

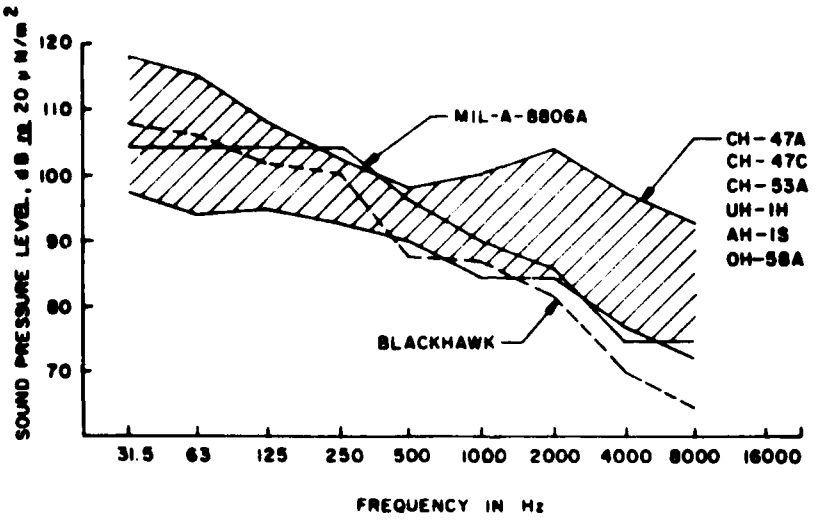

FIGURE 1. Octave Band Pressure Levels in Current Military Helicopters and the Limits of MIL-A-8806A.

It was the intent of the Working Group that the noise limits established would not place undue restrictions on helicopter weight and performance, and that exposure duration during typical missions would be a paramount consideration in determining noise limits. Also, future solutions to noise problems should emphasize noise reduction at the source and limiting acoustic materials in military helicopters to approximately 1% of aircraft gross weight. Emphasis would be placed upon the need to improve helicopter performance while improving communication and hearing conservation.

MISSION PROFILE

Typical noise exposure patterns or scenarios had to be obtained in order to determine the noise levels which should not be exceeded for hearing conservation purposes. Table 1 shows estimates of typical single mission durations for various types of helicopters (5). These data indicate that typical missions range in duration from 1.1 to 2.3 hours.

TABLE 1

Aircrew Exposure Per Mission for Various Helicopters

TYPE HELICOPTER	MISSION PROFILE	MISSION TIME (HOURS)
UTILITY	Combat Troop Extraction	1.3
	Combat Assault	2.3
	Resupply Unit in Contact	1.5
	Aeromedical Evacuation	1.1
SCOUT	Establish Enemy Contact	1.4
	Recon Battle Positions	1.6
	Target Acquisition	1.6
	Screening	2.3
ATTACK	Air-Cav	1.7
	Airmobile Escort	1.6
	Anti-Armor	1.8
CARGO	Logistic Resupply	1.3
ALL	Training	1.8

Table 2 shows the average daily noise exposure times, for a typical number of missions, for peacetime and combat in the four types of helicopters currently in use. Daily aircrew exposure time in combat is two to three times the exposure during peacetime.

TABLE 2

Average Daily Aircrew Exposure during Peacetime and Combat for Various Helicopters

TYPE HELICOPTER	EXPOSURE TIME (FLYING HOURS)	
	PEACETIME	COMBAT
UTILITY	3-6	8-10
SCOUT	2-4	12-14
ATTACK	2-4	8-10
CARGO	2-4	8-10

Comparing the combat exposure times of Table 2 with current hearing damage risk criteria indicates that the expected 10-12 hours of exposure would require noise levels that are unrealistically low from a helicopter design standpoint. It has also been estimated that 95% of hearing loss in military crews and passengers is incurred during peacetime. For these reasons the maximum daily peacetime crew exposure of 4 hours was selected as the basis for determining the hearing damage limits due to helicopter noise.

Based upon the typical mission times for utility and cargo helicopters shown in Table 1, it was estimated that passengers would be exposed for a period of 1.5 hours per day since they normally only participate in a single mission. It was also estimated that many of these exposures might be without hearing protection. It was concluded, therefore, that the limits of the standard should consider both 4 hour exposures for crew members with hearing protection, and 1.5 hour exposures for passengers without hearing protection.

HEARING CONSERVATION

Department of Defense Instruction 6055.3 (6), upon which U.S. Army hearing conservation programs are based, requires that the 8-hour noise exposure level be below 85 dB(A). The Working Group members agreed that the aircraft noise limits should be specified in terms of octave band levels, however, and Category D from MIL-STD-1474B was established as the baseline limit. The limits of Category D are shown in Table 3; an aircraft noise spectrum which does not exceed these values in any octave band will normally be less than 85 dB(A).

TABLE 3

Damage Risk Criteria for Various Exposures, SPH-4 Attenuation and Limits of MIL-A-8806A

Octave Band Center Frequency (Hz)	Category D MIL-STD-1474B 8 Hr Unprot. Level (dB)	1.5 Hr Unprot. Level (dB)	4 Hr Prot. Level (SPH-4 minus 1 σ) (dB)	4 Hr Unprot. Level (dB)	SPH-4 Attn. (dB)	MIL-A-8806A (dB)
31.5	117	127	132	121	-	104
63	106	116	122	110	-	104
125	96	106	112	100	17	104
250	89	99	103	93	15	104
500	83	93	112	87	30	96
1K	80	90	108	84	29	90
2K	79	89	123	83	35	86
4K	79	89	129	83	51	75
8K	81	91	129	85	44	75

Department of Defense Instruction 6055.3 also specifies a 4 dB trading relation between time and intensity. Thus, Table 3 also shows the octave band limits for 1.5- and 4-hour exposures, along with the attenuation values for the aircrewman's helmet (SPH-4). For this application the group decided to subtract one standard deviation from these mean attenuation values. Therefore, the octave band limits for a 4-hour daily exposure when wearing the SPH-4 are shown in Table 3. For comparison the limits of MIL-A-8806A are also provided.

Consideration was also given to including the frequencies of 31.5 Hz and 16 kHz in the standard. It was determined that insufficient data and some controversy presently exists for the inclusion of 31.5 Hz. On the other hand it was agreed that the standard should be extended to include 16 kHz and that, based upon research to date, 89 dB for a 4-hour unprotected exposure should be incorporated.

SPEECH INTELLIGIBILITY

Clearly, when establishing a standard for interior noise, an environment which will enable reliable electrically-aided speech intelligibility must be provided. Effective communications is not only important during normal flight, but is particularly critical during flight emergencies when speech intelligibility may radically affect safety of flight.

The sound pressure level selected for hearing conservation purposes provides an articulation index (AI) of 0.6. This AI will yield electrically-aided intelligibility of 84% using the American National Standards Inst., monosyllabic word intelligibility test (7) which corresponds to 98% sentence and standardized phrase intelligibility (8). The achievement of this intelligibility in helicopters is based upon meeting the noise limits of this standard plus using an aircrewman's helmet which provide the electrical and the attenuation characteristics of the current SPH-4 helmet.

Regarding person-to-person speech intelligibility, it was agreed upon by the Working Group that the noise limit of the standard should permit limited communication providing 75% monosyllabic word intelligibility at 1.5 meters when shouting, and at 0.25 meters when using a normal loud voice. This intelligibility is obtainable if the speech intelligibility level (PSIL-4---the mean of 500, 1000, 2000 and 4000 Hz) does not exceed 85 dB.

DESIGN LIMIT FOR HELICOPTERS UNDER 20,000 lbs.

The octave band levels shown in Figure 2 were selected as the design limit which would meet the aforementioned hearing conservation and speech intelligibility requirements. The individual octave band levels were selected as follows:

1. The SPL selected for 63, 125 and 250 Hz are those which meet the hearing conservation limits for unprotected hearing for a 1.5-hour exposure.

2. The SPL selected for 500, 1000, 2000 and 4000 Hz are those which when averaged will meet the 85 dB PSIL-4 requirement for unaided speech intelligibility.

3. The SPL selected for 8000 Hz is that one which will meet the hearing conservation limits for unprotected hearing for a 4-hour exposure.

4. The SPL selected for 16 kHz is that one which will meet the limit adopted by the American Congress of Governmental Industrial Hygienists for a 4-hour unprotected exposure (9).

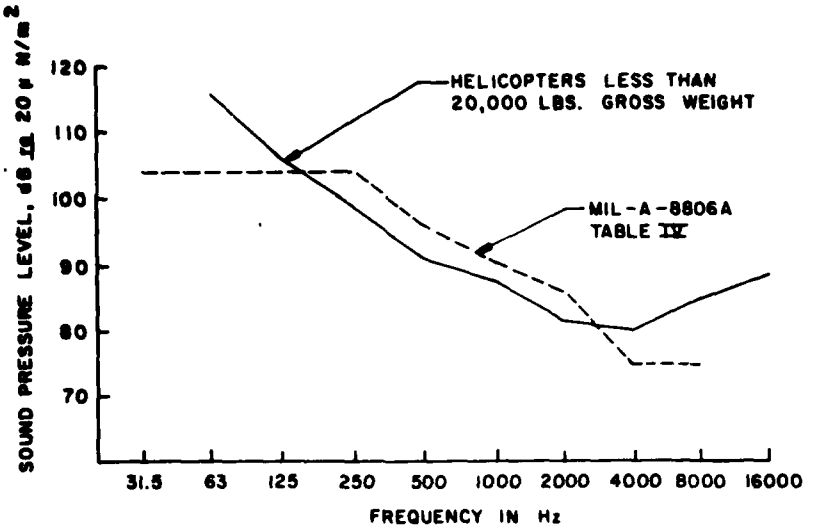

FIGURE 2. Design Limit Helicopters Weighing Less than 20,000 Pounds and the Limit of MIL-A-8806A.

Selection of these levels will also provide adequate electrically-aided speech intelligibility and afford adequate hearing protection for personnel wearing the SPH-4 helmet for up to eight hours, or approved hearing protectors for up to six hours.

For comparison, Figure 2 also shows the limits of MIL-A-8806A. As can be seen the low frequency and high frequency limits of that standard were unnecessarily restrictive. In addition, the levels in the mid-frequencies have been lowered by about 5 dB in order to improve intelligibility and to decrease the potential for hearing loss.

Examination of the selected design criterion of Figure 2 by the Working Group indicates that helicopters weighing more than 20,000 lbs. could not meet this limit even considering state-of-the-art advances. Therefore a separate noise limit was derived for heavy helicopters.

DESIGN LIMIT FOR HELICOPTERS OVER 20,000 lbs.

It was realized when establishing the noise limit for heavy helicopters that a compromise between desirable noise limits and achievable noise levels would be necessary due to the technical difficulties involved in reducing noise. The approach considered in attempting to define the noise limit for heavy helicopters was first to estimate the lowest level achievable through state-of-the-art noise reduction techniques.

As shown in Figure 3, an estimate was made of the reduction in noise level if the CH-47A (28,000 lbs.) type rear fuselage noise treatment was installed in the CH-47C (40,000 lbs.). These levels were further reduced by the attenuation obtained from a transmission noise R&D program (10). Assuming an acoustical treatment of 1% of the gross weight, the estimate is very close to the original quieter CH-47A helicopter data, with elimination of the peak at 2000 Hz. Plotted through the lower levels of these data is a realistically achievable level for a heavy helicopter using 1% of gross weight for noise reduction materials and the latest noise reduction technology.

Superimposed over the realistically achievable level in Figure 4 are the unprotected hearing conservation limits for 1-½ hours and 45 minutes. Although a 1-½ hour limit would be a more desirable goal, the achievable levels for this class of helicopter, appear to be limited to that for the 45 minute exposure. However, this design limit for heavy helicopters would make person-to-person communications at an PSIL-4 of 94 dB almost impossible with a normal loud voice, and would provide difficult communications even when shouting at 0.5 meters.

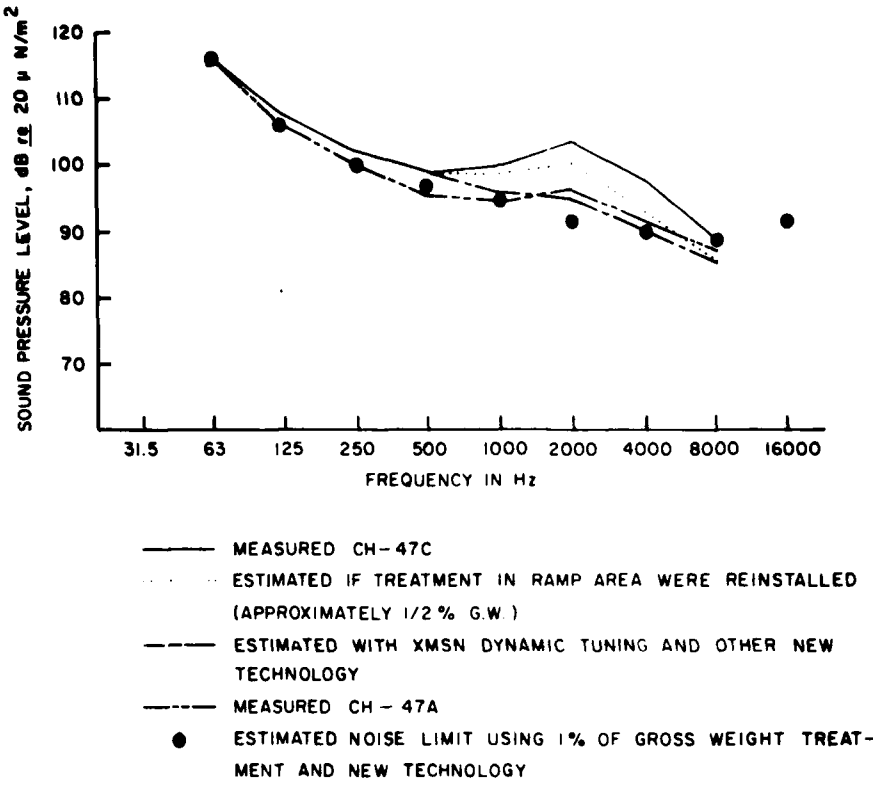

FIGURE 3. Estimated Noise Level Achievable in Heavy Helicopters Using 1% Acoustical Treatment and Using State-of-the-Art Technology.

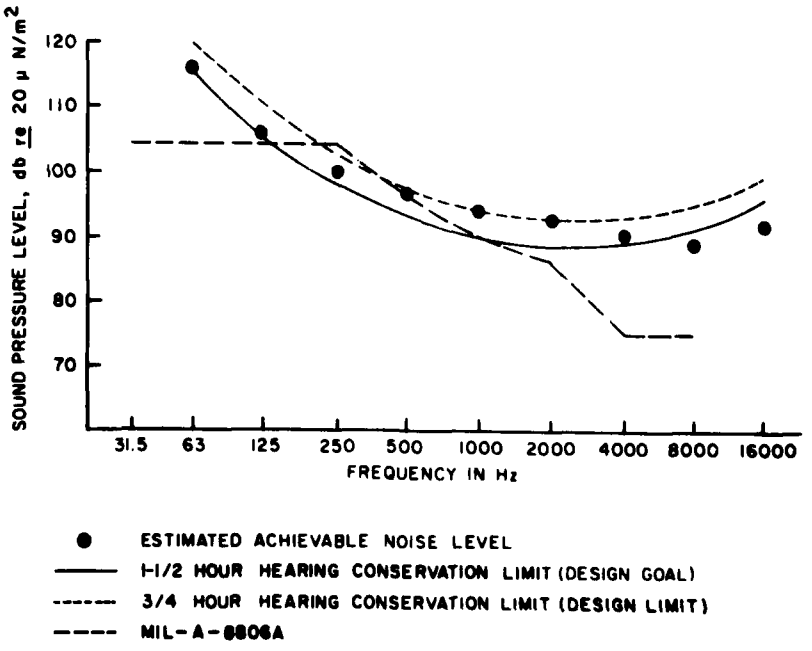

FIGURE 4. Comparison of Hearing Conservation Limit with Estimated Achievable Noise Level for Heavy Helicopters and the Limit of MIL-A-8806A.

Comparison of the 1-½ hour and 45 minute limits with levels of very heavy single rotor helicopters such as the CH-53D (35,000 lbs.) and the CH-53E (60,000 lbs.) indicates that they will have difficulty meeting these limits. Figure 5 illustrates the internal noise level actually measured for the CH-53D and projected for the CH-53E (11). It should be noted that in order to meet a design limit the helicopter noise must not exceed the octave band levels at any frequency.

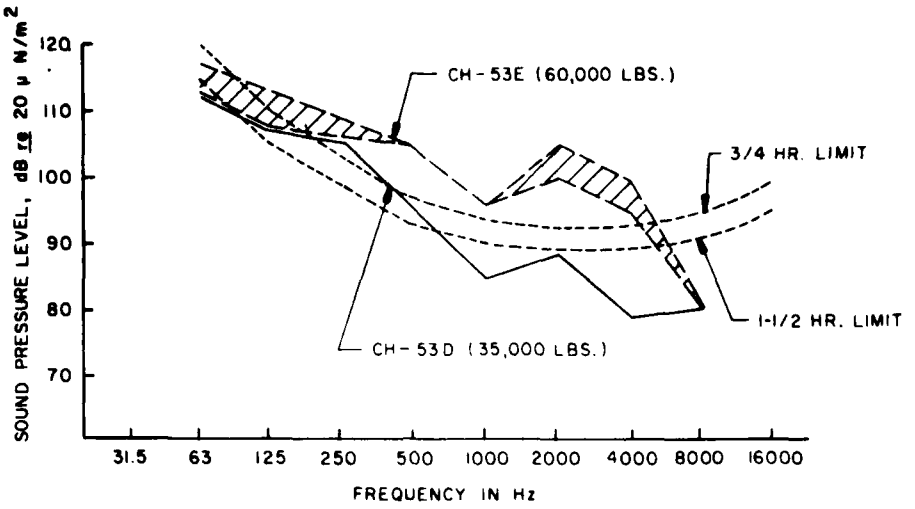

FIGURE 5. Comparison of Hearing Conservation Limit with Noise Level of Two Single Rotor Heavy Helicopters.

In these large helicopters, the lower frequency range of 63-250 Hz is the most difficult to attenuate because of possible rotor blade performance decrements and large amount of barrier material weight required. The mid-to-high frequencies of 500-8000 Hz can be reduced by direct acoustical treatment of main transmissions during design, and selective use of airframe barrier materials and transmission-to-airframe damping.

For the above reasons and to accommodate the very heavy single-rotor helicopters, two curves were established for helicopters weighing more than 20,000 lbs. The higher is called the "design limit" while the lower curve is the "design goal" for the noise of heavy helicopters, Figure 4 shows these two noise limits as well as the design limit of MIL-A-8806A.

It should be noted that ability to reduce noise for this class of helicopter really drove the design limit curve. The hearing conservation limit selected was determined based on achievable limits rather than using hearing conservation considerations to drive development of the curves. Since the "design limit" curve resulted in a 3/4 hour hearing conservation limit, hearing protection will have to be worn by troops and passengers on any flights over 3/4 hours. For aircrew members wearing the SPH-4 helmet, four hours of daily flight mission exposure are permitted, while for passengers wearing approved hearing protection, three hours of daily exposure are permitted. Table 4 shows the limits by octave band for both light and heavy helicopters.

TABLE 4

Helicopter Sound Pressure Level (dB) Design Limits/Goals

OCTAVE BAND CENTER FREQUENCY (dB)	DESIGN GROSS WT. LESS THAN 20,000 LBS. DESIGN LIMIT	DESIGN GROSS WT. 20,000 LBS. OR GREATER DESIGN GOAL	DESIGN LIMIT
63	116	116	120
125	106	106	110
250	99	99	103
500	91	93	97
1000	87	90	94
2000	82	89	93
4000	80	89	93
8000	85	91	95
16000	89	95	99

The development of the "design goal" was influenced by a desire to meet the 1-½ hour hearing conservation limit required for unprotected passengers as well as to provide the goal of a tolerable environment for unaided communication. It is intended that this "design goal" would be used to advance the state-of-the-art in noise reduction technology and to provide aircraft contractors with a financial or competitive incentive to reduce noise to more acceptable levels.

AIRCRAFT SUBSYSTEM NOISE

In some aircraft subsystem, equipment which operates while in flight such as oil pumps, on-board auxiliary power units, blowers, etc., may produce significant noise levels. Therefore, this standard requires that the noise generated by those systems, while in flight, will not exceed the helicopter noise limit. The fact that government furnished equipment or commercial equipment may significantly contribute to the noise level, does not eliminate the requirement that the total system noise conform to the standard. The contractor is required to apply appropriate noise reduction techniques or place the equipment in such a manner that the noise limits are met.

MEASUREMENT AND EVALUATION

The conditions under which helicopter noise will be measured are separated into two sections in the standard. The first section provides those data that must be obtained to verify contract compliance. For compliance, measurements are made at selected crew and passenger locations when hovering and in normal level flight with all doors, windows and vents closed, and with acoustic treatment in place.

The second set of data are for information purposes and are designed to:

1. Determine the effect of opening doors, windows and vents.

2. Determine the noise exposure of ground and maintenance personnel.

3. Provide data to verify the adequacy of electronic communications equipment.

Noise measurement procedures are precisely defined in the standard, as well as the instrumentation characteristics and the instrumentation techniques to be used. The procedures presented reflect the most current noise measurement techniques available. These 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. Data to be reported are clearly defined, and include such items as: instrumentation, weather conditions, calibration method, etc.

It is intended that this standard will provide the measurement procedures and noise limits by which reasonable noise levels can be achieved inside helicopters. These noise levels were established to represent a reasonable compromise between those levels which current state-of-the-art permits the designer to achieve in helicopters, and those levels which will minimize hearing damage risk and maximize speech intelligibility.

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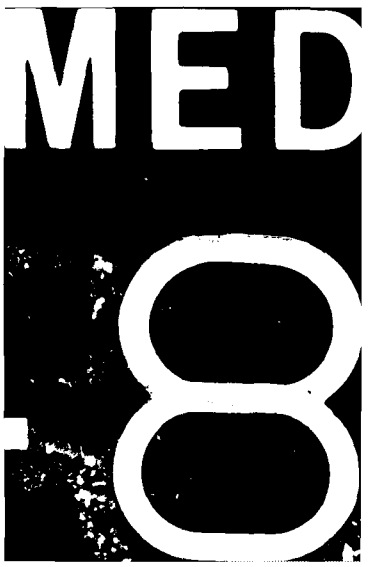
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