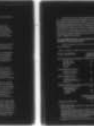
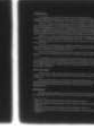


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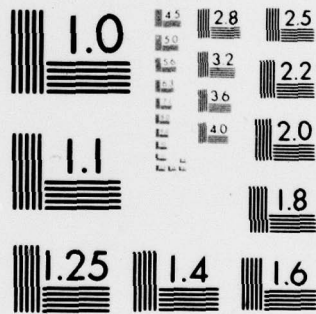
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Technical Document 257

NOISE ON US MERCHANT SHIPS

A summary of the problem with recommended limits and future work

RS Gales
DR Schmidt
DR Lambert

30 April 1979

Prepared for
US Coast Guard
Office of Research and Development
Washington DC 20590

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Technical Director

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) This document is an overview of a study performed for the US Coast Guard to provide an information base and recommendations for the establishment of noise limits for US merchant ships. The study consisted of (1) a search of the literature on the effects of noise on humans and existing data on noise aboard US merchant ships, (2) a review of existing and proposed noise standards, (3) measurement of the noise and noise exposure of the crew aboard seven representative US merchant ships, and (4) preparation of recommendations for noise limits on US merchant ships.		

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FOREWORD

This document has been prepared for the US Coast Guard for general guidance in the development of noise standards for US merchant ships. It is an overview of several reports dealing with various aspects of noise as related to the habitability and safety of personnel aboard merchant ships.

The contents of this document, including its recommendations, are the responsibility of the authors and should not be construed as representing official Navy policy.

EXECUTIVE SUMMARY

This document is an overview of a study performed for the US Coast Guard to provide an information base and recommendations for the establishment of noise limits for US merchant ships.

The study consisted of four parts:

- A search of the literature on the effects of noise on humans and on existing data concerning noise aboard US merchant ships.
- A review of existing and proposed noise standards.
- Measurement of the noise and noise exposure of the crew aboard seven representative US merchant ships.
- Preparation of recommendations for noise limits on US merchant ships.

Shipboard noise presents problems of four general types:

Hearing damage to engine room personnel.

Interference with speech communication.

Interference with hearing warning signals.

Interference with rest, sleep, and recovery from temporary hearing loss sustained on duty in noisy spaces.

Criteria are available in the literature to enable limits to be set for each of these types of noise problems. A suitable noise measure or "descriptor" is selected that correlates well with the effects to be controlled. A-weighted sound level is recommended as a general descriptor for all effects. To take into account the effect of the duration of the exposure, an important factor in preventing hearing damage, a time-averaged form of A-weighted sound level, called the equivalent continuous sound level for a 24-hour period (L_{eq24}), is proposed as the descriptor for hearing conservation. Limit values of A-weighted sound levels for assuring adequate speech intelligibility, for hearing warning signals, and for rest and recovery are presented; also given are limits of the 24-hour equivalent continuous sound level for hearing conservation. Activation of the limits in two steps is proposed:

Immediate slightly lenient limits to apply to existing ships.

More stringent limits for future application to new ships.

Data are presented on noise measured in late 1978 on six US merchant ships whose construction dates are distributed over the last 20 years and on one built in the 1920s. The ships include tankers, bulk cargo ships, container cargo ships, and ore carriers. Power plants were steam turbine, gas turbine, or diesel. All vessels were rated over 5000 gross tons.

Noise exposures of engine-room personnel without ear protection on all ships exceeded the proposed hearing damage criterion of 80 dB L_{eq24} . The noise reduction provided by properly fitted commercially available ear protectors may be expected to reduce exposures to safe levels. Noise exposures of all non-engine-room personnel were well within safe limits with regard to hearing damage; ear protection was unneeded.

In general, noise levels in nonmachinery spaces (bridge, sleeping, messing, recreating, office areas, etc) meet the recommended limits of A-weighted sound level. On two ships, however, some staterooms were found to exceed slightly the proposed limit of 65 dB(A).

Proposed limits for existing US ships were compared with limits specified by foreign nations. The foreign criteria are generally equal or less stringent for hearing conservation, but tend to be either equal or more stringent for functions other than hearing conservation.

Suggestions for future work include the following:

Survey additional ships to obtain a more representative data base on existing US ships.

Measure actual 24-hour noise exposure of the engineering crew by use of wearable noise dosimeters.

Prepare standard procedures for noise inspections of merchant ships.

Study adequacy of present sleep criteria to deal with transient and intermittent noise such as hatch and door slams, noises in passageways, and opening of engine room casing doors.

Survey vibration on a representative sample of US merchant ships and recommend vibration limits if they are felt to be needed.

In addition to the documentation included in this report, a comprehensive annotated bibliography entitled Behavioral and Physiological Effects of Noise on People – Supplementary Bibliography (ref 1) has been prepared and is available for reference from NOSC Code 5121 or from Coast Guard Headquarters, Washington, DC.

¹ Behavioral and Physiological Effects of Noise on People – Supplementary Bibliography, an unpublished paper by DR Lambert and FS Hafner, NOSC Code 5121, January 1979.

CONTENTS

INTRODUCTION . . . page 4

EFFECTS OF NOISE . . . 4

Hearing damage . . . 4

Interference with speech communication . . . 5

Interference with warning signals . . . 6

Rest and recovery from temporary hearing loss . . . 6

REPORTING OF DATA . . . 6

RELATIONSHIP BETWEEN NOSC RECOMMENDED CRITERIA AND
MEASURED DATA . . . 7

COMPARISON OF NOSC RECOMMENDED CRITERIA WITH FOREIGN CRITERIA . . . 8

SUGGESTED FUTURE WORK . . . 9

REFERENCES . . . 11

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INTRODUCTION

This document is an overview of a study of noise on US merchant ships. It summarizes and relates the findings of five documents (ref 1-5) that have been prepared in connection with the study. The contents of the documents are summarized as follows:

Reference 2 contains a brief presentation of the overall problem of establishing noise criteria and presents a set of recommended criteria for acceptable noise in US merchant ships. The recommendations are based on a combination of (1) the effects of noise on humans, (2) proposed and existing noise criteria and standards, (3) an available published data base of shipboard noise levels, (4) measurements made by NOSC on seven US merchant ships specifically for this study, and (5) the engineering practicability of noise reduction.

Reference 3 is a review of the literature on the effects of noise on people, which is supported by an annotated supplementary bibliography. (Reference 1 is that bibliography.)

Reference 4 tabulates noise level data collected from the literature on US and non-US merchant ships.

Reference 5 presents data from current NOSC measurements of seven US merchant ships, gives computed noise exposure levels of personnel, and compares these levels with the noise and exposure criteria recommended in reference 2.

This document summarizes the proposed criteria, briefly restates the background on which they are based, and briefly discusses measures of shipboard noise and its effects on people.

For uniformity and ease of comparison, the single descriptor, dB(A) (the A-weighted sound level in decibels), has been used throughout this report. This follows the recommendation of Working Group S3-47 of the American National Standards Institute (ANSI) to use A-weighted sound level as a common measure in quantitatively relating levels of sounds to their effects on humans.

EFFECTS OF NOISE

Airborne noise on ships causes several different types of problems. They differ as to importance and solution. Background information on the effects of noise on people is given in reference 3.

Noise is of critical importance to the safety of personnel and ships because it can cause hearing damage and can interfere with speech communication, the hearing of warning signals, rest, and recovery from temporary hearing loss. These and other effects are summarized below.

Hearing Damage

Personnel exposed to high-level noise like that in engine rooms often suffer hearing loss, particularly when exposed for long periods. This loss, which may be temporary or

² NOSC TD 254, Airborne Noise Limits for Merchant Ships, by RS Gales, 30 April 1979.

³ NOSC TD 267, Behavioral and Physiological Effects of Noise on People, by DR Lambert and FS Hafner, 30 April 1979.

⁴ NOSC TD 243, Airborne Noise Levels on Merchant Ships, by DR Lambert, 30 April 1979.

⁵ NOSC TR 405, Noise Levels and Crew Noise Exposure Aboard US Merchant Vessels, by DR Schmidt, 30 April 1979.

permanent, is described quantitatively as decibels of temporary threshold shift (TTS) or permanent threshold shift (PTS).

The amount of hearing damage depends on the level and frequency spectrum of the noise, the duration of exposure, the availability of quiet periods for recovery, and the susceptibility of the exposed person.

The permissible duration of noise exposure decreases as the level increases. Reference 3 describes the time-intensity trade-off relationship of noise exposure – that is, the added length of exposure time allowable in noise when its level is reduced a given number of decibels. Reference 2 recommends a time-intensity trade-off of 3 dB(A) per time halving. (This is the “equal energy” rule.)

Exposure duration may be reduced through administrative controls such as the adjustment of watch schedules. The allowable duration increases as the number of breaks in the noise increases, assuming that breaks are spent in effective quiet (levels not exceeding 70 dB(A)).

Criteria for levels in ship spaces will be an important part of hearing conservation efforts on merchant ships. But it may not be feasible to reduce the exposure level of personnel to acceptable levels by reducing engine-room noise with engineering controls alone, either in existing ships or in future construction. The use of isolated control rooms, for example, has proven to be an effective way of reducing noise exposure, but it may not always be practical for existing ships.

Consequently, it is recommended that hearing conservation criteria on merchant ships be focused primarily on reducing exposure of the ear to damaging noise rather than on reducing the noise in the ship spaces. Specifically, it is proposed that criteria be based on 24-hour equivalent continuous sound level (L_{eq24}).^{*} This takes into account the total noise environment of an individual.

As literature data and NOSC measurements show, the recommended criteria for machinery spaces can be met with the effective use of hearing protection. It must be kept in mind, however, that for reasons of comfort, health, or safety, hearing protection is often not worn. Machinery personnel often state that they cannot wear hearing protection because it interferes with their ability to hear machinery sounds (“cues”) which indicate impending malfunction.

Because of the great variability of individual susceptibility to noise-induced hearing loss, it is necessary to base criteria on the concept of protecting a given percentage of the population. This is often presented as a percent risk, ie, the percent of exposed persons expected to receive a hearing impairment in excess of that expected in a non-noise-exposed person of the same age. For personnel exposed to very noisy tasks, noise damage may be identified through regular audiometric examinations. Those showing incipient hearing damage should be reassigned elsewhere unless their exposure can be reduced to an acceptable level. Personnel considering shipboard engineering as a career should be informed that high noise levels tend to cause progressive hearing loss in individuals sensitive to noise. Persons showing a sensitivity to noise-induced hearing loss should be encouraged to pursue other occupations.

Interference with Speech Communication

Noise interferes with, or masks, the hearing of speech. This is particularly important to the safety and efficient operation of the ship at such locations as the bridge, radio room,

^{*} Equivalent continuous sound level (L_{eq}) of a given sound (which may fluctuate in level) is that level of a steady sound which has the same total energy over a specified time duration. This is sometimes called the average sound level.

engine control room and other locations where commands and other voice communications vital to the operation of the ship must be heard accurately.

Interference with Warning Signals

Noise often masks the audibility of warning signals, such as bells and buzzers pertaining to own ship alarms, and may interfere with the hearing of off-ship warnings such as whistles, foghorns, diaphones, etc. Quiet is particularly important at the lookout and bridge locations for hearing off-ship warning signals critical to the safety of other ships as well as one's own ship. The high sound level of the own-ship whistle or foghorn may produce a temporary hearing loss in own-ship personnel which may interfere with hearing warning signals.

Rest and Recovery from Temporary Hearing Loss

Noise in areas for rest and relaxation, such as lounges and sleeping quarters, must be sufficiently low to allow recovery from temporary threshold shift acquired during duty in noisy areas, to allow adequate sleep, and to prevent adverse noise-related health and physiological effects sometimes observed in circulatory and nervous systems.

Personnel whose sleep is disturbed by noise may suffer degraded work performance and health. Steady or regular periodic noises appear to have very little effect on sleep or work performance. People appear to adapt to noise unless it is aperiodic or intermittent, or unless they are already performing at the limits of their capacity. But recent physiological research suggests that the cardiovascular system response may never adapt (ref 3).

REPORTING OF DATA

A measurement procedure often used in reporting airborne noise gives complete octave band, A-, and C-weighted sound pressure levels for each space measured on every ship. This provides a high degree of flexibility, allowing each user to combine data from many sources and to compute all desired statistics. But since it becomes burdensome when great amounts of data are involved, recent trends have been to select less burdensome alternatives such as using the A-weighted sound level, alone or supplemented by C-weighted measurements.

This study recommends the use of the A-weighted sound pressure level. In most cases, the A level does a commendable job, although it does not provide the detailed information often needed for diagnosis and solution of a specific noise problem. It is important that the user recognize and accept the fact that A-weighting represents a compromise with at least the following advantages: (1) It is a single number, simple and inexpensive to measure and analyze, (2) it is relatively easy for shipboard personnel or the general public to understand, and (3) it is meaningful – the literature generally supports its use in determining the effects of noise on people (eg, hearing damage risk, speech interference) (ref 3).

Some investigators prefer to supplement the A level with the C level because, unlike most common spectra, shipboard spaces often contain strong low-frequency components to which the A level is not very sensitive. The numerical difference between the A and C levels (C-A), often serves as a useful measure of low-frequency content. The NOSC data (ref 4, 5) support the finding of previous literature that C-A is generally large (eg, 10 to 30 dB) in the upper sections of the ship such as the bridge and accommodation spaces, but low (eg, 0 to 10 dB) in engineering spaces. This indicates that, in general, A-weighting is a good measure of noise in machinery spaces, and that one may assume the presence of relatively strong low-frequency components in other areas.

Some prefer to use the noise rating (NR), which is a single number rating obtained from a series of noise rating curves applied to octave-band measurements. Although it is more responsive to high-level low-frequency components than A-weighting, it has the disadvantage of being burdensome since it requires octave-band measurements. Also, NOSC Technical Report NELC TR 1314 (ref 6) showed that a type of rating using a family of curves, similar to the NR, was inferior to A-weighted sound level for determining speech interference. It is not possible to compute A-weighted sound level from NR accurately (ref 7), since they depend in different ways on the octave-band spectrum. However, a rule of thumb often used for shipboard noise is that the A-weighted sound level in dB is approximately 5 dB higher than the NR.

RELATIONSHIP BETWEEN NOSC RECOMMENDED CRITERIA AND MEASURED DATA

Table 1 summarizes the NOSC criteria recommended in reference 2, for noise aboard US merchant ships.

Table 1. Summary of NOSC criteria for US merchant ships recommended in reference 2.

<u>ACTIVITY AND SHIP SPACE</u>	<u>A-WEIGHTED SOUND LEVEL IN dB (dB(A)) FOR:</u>	
	<u>EXISTING SHIPS</u>	<u>FUTURE (1985) GOAL</u>
REST, RECOVERY FROM TEMPORARY HEARING LOSS, AND SLEEP		
Mess/Rec Room	70	65
Office/Day Cabins	70	65
Sleep Cabins	65	60
Hospital	65	60
HEARING WARNING SIGNALS		
Whistle at listening posts	110	100
Listening post lookout	70	65
SPEECH COMMUNICATION		
Engine control room	80	75
Enclosed bridge/wheelhouse	65	60
Radio room	70	65
HEARING CONSERVATION (BASED ON 8-HOUR DAY)		
Manned machinery spaces	85*	80
Periodically manned machinery spaces	110*	105
Workshops	85*	80
24-HOUR EQUIVALENT CONTINUOUS SOUND LEVEL IN dB (A)		
	<u>EXISTING SHIPS</u>	<u>FUTURE (1985) GOAL</u>
HEARING CONSERVATION	80	75

⁶ NOSC Technical Report NELC TR 1314, Speech Interfering Aspects of Navy Noises, by JC Webster and RG Klumpp, 1965.

⁷ A Survey of Noise in Merchant Ships, by RB Conn; Trans of North East Coast Institution of Engineers and Shipbuilders, vol 85 no 4, p 61-71, 20 January 1969. Conn computed the difference between the measured A levels and the A levels he estimated by applying an additive constant of 2.5 dB to the NR values. He reports that for machinery spaces, differences of ± 4 dB are likely and ± 9 dB are possible; for bridges, one may expect twice this difference.

* Hearing protection required in all areas in which the sound level exceeds 85 dB(A).

A comparison of the NOSC recommended space-level criteria with the NOSC measured data (ref 5) and data for US ships taken from the literature (ref 4) shows that almost all the nonmachinery spaces met the recommended criteria for current ships.

Of the NOSC measured ship spaces reported in reference 5, the only nonmachinery spaces to exceed the NOSC recommended criteria were staterooms. Only 6 of 34 measured spaces exceeded the 65 dB(A) criterion, and none of these by more than 5 dB. Of the other US data reported in reference 4, only one ship had staterooms which exceeded the recommended criterion of 65 dB(A), and this ship exceeded it by only 1 dB. Other nonmachinery spaces such as the bridge, radio room, mess and recreation rooms, and offices and day cabins all met the recommended criteria.

During the NOSC measurements observers noted that machinery space levels were usually steady, varying only moderately in level when speed was changed. Examination of the NOSC machinery space data (ref 5) shows that all the spaces measured would meet the NOSC recommended criterion for current ships of 85 dB(A) for 8 hours work exposure, provided that 20 dB(A) of effective hearing protection were worn by the engine-room watch personnel. Likewise, the US ship measurements taken from the literature (ref 4) show that all could meet the criterion if hearing protection affording 20 dB(A) of effective protection were worn.

Reference 5 compares US (NOSC) calculated exposure levels with the NOSC recommended exposure limits. All personnel on all ships would meet the recommended criteria of an L_{eq24} of 80 dB(A) if hearing protection affording 20 dB(A) of effective protection were worn in machinery spaces. Ships OD-1 and TG-1, measured by NOSC, have isolated machinery control rooms with sound levels of 86 and 56 dB(A) respectively at the engineering control stations. Such control rooms are a great aid in keeping the exposure of watch standers at safe levels on ships such as OD-1 and TG-1, which have levels of 108 and 102 dB(A) in the machinery spaces, as shown in table 8 of reference 4.

COMPARISON OF NOSC RECOMMENDED CRITERIA WITH FOREIGN CRITERIA

Table 2 lists a comparison of NOSC recommended criteria for existing ships and present foreign criteria from reference 2. It presents the number of foreign criteria that are less stringent, equal to, or more stringent than the NOSC criteria that have been given in table 1. For example, in manned machinery spaces, one foreign criterion was more stringent (ie, specified a lower allowable level) than the NOSC criterion, one was equal to the NOSC criterion, and six were less stringent (ie, specified a higher allowable level) than the NOSC criterion. Numbers will not total the same for each type of space since not all countries had established criteria for all types of spaces listed.

The criteria that are compared with NOSC criteria are those from Britain, Denmark, Finland, W Germany, Israel, Netherlands, Norway, Sweden, and the USSR.

Table 2. Comparison of present foreign criteria with NOSC criteria for existing ships.

<u>ACTIVITY AND SHIP SPACE</u>	<u>NUMBER OF FOREIGN CRITERIA THAT WERE:</u>		
	<u>MORE STRINGENT</u>	<u>EQUAL</u>	<u>LESS STRINGENT</u>
	<u>THAN</u>	<u>TO</u>	<u>THAN</u>
	<u>THE CORRESPONDING NOSC CRITERION</u>		
REST, RECOVERY FROM TEMPORARY HEARING LOSS, AND SLEEP			
Mess/Rec Room	6	1	1
Office/Day Cabins	6	0	0
Sleep Cabins	7	0	1
Hospital	3	0	0
HEARING WARNING SIGNALS			
Whistle at listening posts	0	2	0
Listening post lookout	1	4	0
SPEECH COMMUNICATION			
Engine control room	4	2	0
Enclosed bridge/wheelhouse	2	4	1
Radio room	7	1	0
HEARING CONSERVATION (BASED ON 8-HOUR DAY)			
Manned machinery spaces	1	1	6
Periodically manned <i>machinery spaces</i>	2	5	0
Workshops	2	3	3

SUGGESTED FUTURE WORK

1. **DATA BASE ON NOISE ON US MERCHANT SHIPS.** Increase the size of the data base on US merchant ships by measuring noise on at least 25 additional ships selected to sample a wider variety of ship types, propulsion, and construction. Survey should include measurements with integrating (dosimeter type) meters.

2. **DOSIMETER STUDY OF NOISE EXPOSURE OF CREW.** Obtain a broad sample of data of noise exposure of the crew by providing them with wearable dosimeters. These will provide an accurate measure of the total exposure in both duty and nonduty areas.

3. **COMPARISON OF CALCULATED AND MEASURED EXPOSURE LEVELS.** Check the validity of the 24-hour equivalent level data calculated from measured sound levels and time in spaces as obtained from crew questionnaires (ref 5) by comparing them with values measured directly by an integrating sound level meter or dosimeter.

4. **SLEEP CRITERIA STUDY.** Conduct a laboratory study to determine the optimum level of noise for sleeping aboard ships. Criteria for sleeping quarters vary from 50 dB(A) (USSR) to 70 dB(A) (USN). There is almost no research available to assist in deciding on an optimum value (ref 2, 3). Too low a level causes problems of awakening due to various intrusive noises such as door slams, voices in the passageways, engine noise associated with the opening of casing doors, etc. Too high a level, on the other hand, even though it may be steady and may beneficially mask intrusive awakening sounds, may have

certain adverse effects such as reducing the audibility of alarms and warning signals, slowing the recovery from TTS, and production of various physiological responses which may or may not be deleterious (ref 2, 3).

5. NOISE MEASUREMENT PROCEDURES FOR INSPECTION OF MERCHANT SHIPS. Prepare standard procedures in terms of equipment, measurement locations, ship operating conditions, qualification of measurement technicians, etc. These should be validated by actual field use on a small representative sample of ships.

6. REFINEMENT OF THE USE OF A-WEIGHTED SOUND LEVEL. Identify possible limitations of the A level on ships (exhaust noise on bridge wings, tonal components due to defective generator reduction gear whine, and others, if any) and develop specifications for recognizing them. Develop appropriate supplementary procedures.

7. STUDY OF MACHINERY CUES. Conduct a study on merchant ships to supplement an ongoing Navy project currently being conducted under sponsorship of the Ship Silencing Division of the Naval Sea Systems Command. Machinery personnel often state that it is important for them to be able to hear sounds made by machinery in order to maintain it, and that hearing protectors prevent them from receiving those cues. Research is needed to determine the validity of this claim.

8. VIBRATION ON US MERCHANT SHIPS. Obtain vibration measurements and compute a combined noise-vibration rating of habitability on US merchant ships. Vibration is an important element of ship habitability. AB Lewis (ref 8) notes that dual criteria combining both noise and vibration measures have been proposed for shipboard annoyance ratings.

⁸ Some Aspects of Noise and Vibration On Board Tankers, by AB Lewis; Noise Control Engineering, vol 7 no 3, p 132, 1976.

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