System Safety Implications and Applications of Noise Evaluation and Control in Military Ships

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Abstract: Noise associated hearing loss is considered the most common occupational health exposure in general industry and poses particular risk in defense systems and equipment. Impacts may include fiscal considerations (workers compensation and veteran's benefits), decreased communications in combat situations and social environments and increased vulnerability to external detection. Measures to manage hearing loss through aggressive hearing conservation program focusing upon training, protective equipment use and medical monitoring have met with varied and often limited success. System safety assessments have not consistently considered noise and vibration generation and the related human health and performance effects. However, cost-effective technologies for noise controls offer the potential to reduce the human, military and social impacts of hearing loss. Recommendations are made to address noise in the systems requirements and engineering management process and ensure risk evaluation and mitigation of noise generation and human exposures at a management level consistent with their severity.

Introduction:

Noise exposure and associated hearing loss has long been regarded as the most common occupational health hazard in general industry. Earlier evaluations, summarized by the National Institute for Occupational Safety and Health estimated that 7.9 to 9.1 million US workers are exposed to noise at levels that have the potential to create occupational hearing loss [1], Table 1. Current reviews [2] suggest that as many as 30 million workers may have periodic noise exposures that place them at potential risk for hearing loss**.** The American Academy of Audio logy acknowledges the range of estimates varies between 5 and 30 million [3]. Many exposures to noise and various chemical agents, such as certain solvents or drugs such as antibiotics of the mycin class, may create synergistic effects. Current research is evaluating the potential link between combined effects of noise and chemical agents such as solvents on hearing loss. Literature review suggests that as many as 3 million are at risk from hearing loss associated concurrent exposure to chemical agents such as carbon monoxide and noise [2]

Table 1 Estimated Numbers of Noise Exposed Workers in the United States*

Major Group	Estimated Number Exposed to Occupational Noise	Criteria for Exposure	Date of Evaluation	Source
U.S. Manufacturing Workers	7.9 Million	Exposure at or above 80 dBA	1981	OSHA 46 Fed. Reg. 4078 [1981a]. U.S. Department of Labor: occupational noise exposure; hearing conservation amendment; final rule. (Codified at 29 CFR 1910.95)
All US workers	9.125 Million 976 Thousand Military (More than half in manufacturing and utilities	Exposure at or above 85 dBA	1981	Environmental Protection Agency EPA Report No. 550/9-81-101
U.S Production Workers (Industrial settings)	4.098 Million (16.9 % of 24.25 Million production workers) 199 Thousand (85% of 236 Thousand in Mining associated industries)	Periodic noise exposures at or above 85 dBA in 90% of workweeks.	1988	NIOSH 1988 (National Occupational Exposure Survey 1981-83 of general industry Supplemented by 1984-1989 review of mining industry (NIOSH) Publication No. 89-103.

* As summarized in NIOSH Criteria for Recommended Noise Standard 1998, reference [1], paragraph 2.4

Despite the variance in statistics, most references concur in several common conclusions:
- Unabated noise exposure will result in an unacceptable rate of hearing loss.

- The social and economic effects of hearing impairment are severe both for society and the individuals affected
- Occupational hearing loss is almost entirely preventable and therefore should be considered socially unacceptable.
- Engineering and design controls are the preferred method of controlling exposure.
- Effectiveness of hearing protection equipment is typically markedly less than the rated sound attenuation and is very dependent upon equipment selection, training, motivation and enforcement.
- Use of hearing protection and associated audiology and training programs are essential where noise control is not feasible.

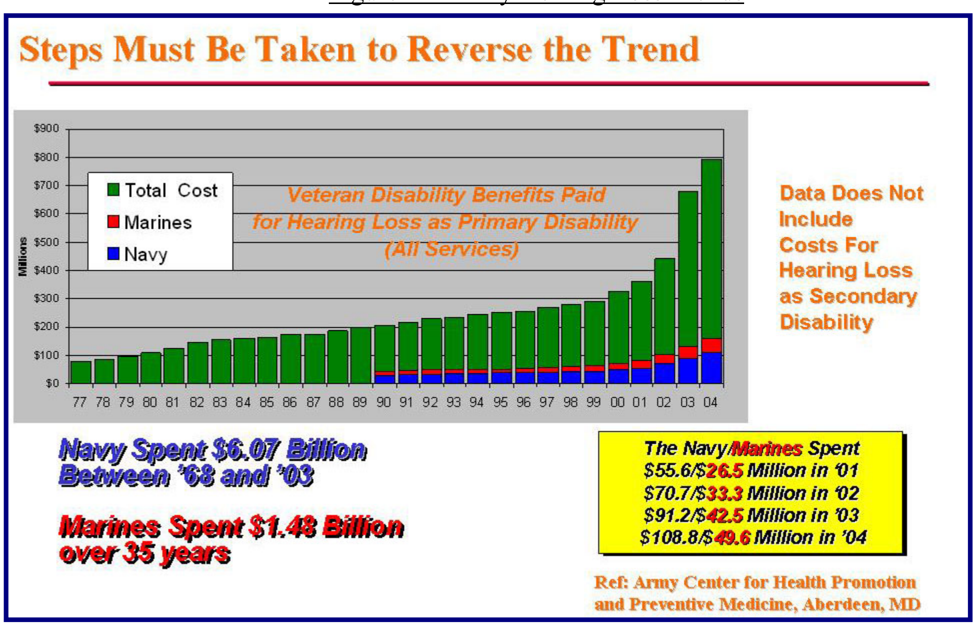
Noise Exposure and Hearing Loss in the Military

A significant fraction of military equipment and operations are associated with particularly pervasive and severe noise hazards. Maintenance of military equipment, operation of platforms ranging from aircraft to combat vehicles and weapons training and combat operation all involves high levels of noise exposure. Hearing loss is the most common service associated disability [4]. Dr. Ohlin US Army Center for Health Promotion and Preventative Medicine, Aberdeen Proving Grounds, examined VA data, which details the breakdown of the costs by associated Service Branch [4], [5]. The breakout of hearing compensation cost (2003) for each service is shown in Table 1. The cost over two decades for all services is $3.6B and continues to grow, as shown in Figure (1).

Table 1 Hearing Compensation Cost Breakdown (2003)

2003	Cases (primary)	Cost (primary)
Army	42,825	$337.3M
Navy	13,892	$ 91.2M
Air Force	10,531	$ 68.9M
USMC	5,838	$ 42.5M
Total	73,086	$539.9M

Figure 1 Military Hearing Loss Trends



Noise Exposure and Hearing Loss

Occupational exposure criteria are established on the basis of their ability to prevent hearing loss and/or other health impairment [1], [6], [7] and typically represent a compromise between desired protection and economic and political factors. Commonly applied occupational exposure criteria are summarized in Table 2. The National Institute of

Occupational Safety and Health [1] as well as the American Conference of Governmental Industrial Hygienists [6] recommend an allowable exposure level of 85 dBA for 8 hours (time weighted average) because this limiting exposures to this level over a working lifetime is estimated to result in a hearing loss risk of "only" 8% above that of the unexposed general population. In contrast, application of the OSHA Permissible Exposure Limit of 90 dBA 8-hour time weighted average exposure is estimated to result in a rate of hearing loss of 25% above that of the non-exposed population. The DOD Standard [8] of 85 dBA 8-hour time weighted average with a 4 dBA doubling rate.

Table 2 Allowable Noise Exposures

Exposure Standard Source	OSHA [Ref 7]	ACGIH [Ref 6] and NIOSH [Ref 1]	DOD [Ref 8]
Doubling rate	5 dB	3 dB	4 dB
Allowable exposure for 16 hours Weighted Average (TWA)	85 dBA	82 dBA	80 dBA
Allowable 8-hour Time Weighted Average (TWA)	**90 dBA**	**85 dBA**	**85 dBA**
Rate of "excess" hearing loss associated with life-time occupational exposure at 8 hour TWA [Ref 1]	**25%**	**8 %**	
Allowable 4 hour TWA	95 dBA	88 dBA	87 dBA
Allowable 2 hour TWA	100 dBA	91 dBA	91 dBA
Allowable 1 hour TWA	105 dBA	92 dBA	95 dBA

(For unprotected noise exposures of the described intensity or Considering De-rated effectiveness of hearing protective equipment)

<u>Not So Protective Equipment – Not So Easy to Implement</u>:

The limitations of relying upon protective equipment, as a primary means of noise "control" must be confronted because of common misunderstandings related to the effectiveness of this approach. The limitations associated with protective equipment and the administrative burden their use imposes, are consistently underestimated. The high rate of hearing loss among military and associated civilian workers despite the organizational presence of an aggressive hearing conservation program in DOD makes limitations of predominant reliance on protective equipment and support educational and medical monitoring programs, particularly evident.

The order of precedence in Military Standard 882 [9], and virtually all occupational safety and health guidance, requires that substitution of less hazardous processes and materials and engineering controls for residual hazards be considered as the first and optimal measures to reduce safety risks. The DOD Hearing Conservation instruction specifically states that procedures, training and protective equipment are considered the less effective alternatives and are to be used where engineering controls are not practical or fully protective [8]. Responsibilities for management of noise hazards in DOD are specifically assigned to the Undersecretary of Defense for Acquisition Technology and Logistics [Ref 8, paragraph 5.a.], and application of Military Standard 882 risk assessment criteria is specifically <u>required</u>.

Additionally, OSHA standards for protective equipment [29 CFR 1910.134] and hearing conservation [7] specifically require consideration of alternatives to protective equipment use. Where protective equipment is necessary, development of written programs; process review; identification of alternative control measures; clear specification of required protective equipment; ensuring compliance with relevant design (typically ANSI or NIOSH) standards and testing; associated training; medical evaluation (for users of hearing protection and respiratory protection); equipment inspection and periodic program review.

The OSHA hearing conservation standard [7] imposes detailed requirements for estimating the actual effectiveness of hearing protective equipment. For example, when no detailed data is available, the least involved approach requires that 7 dB be deducted from the Noise Reduction Rating (NRR) associated with the specific protective equipment used. In practice, hearing protection often provides even less effective protection. In the absence of individual data (measurements on individual workers), NIOSH criteria for noise exposure [1] recommend de-rating of the stated NRR as follows; earmuffs 25%; formable earplugs 50% of NRR; other earplugs are de-rated by 75% of the NRR.

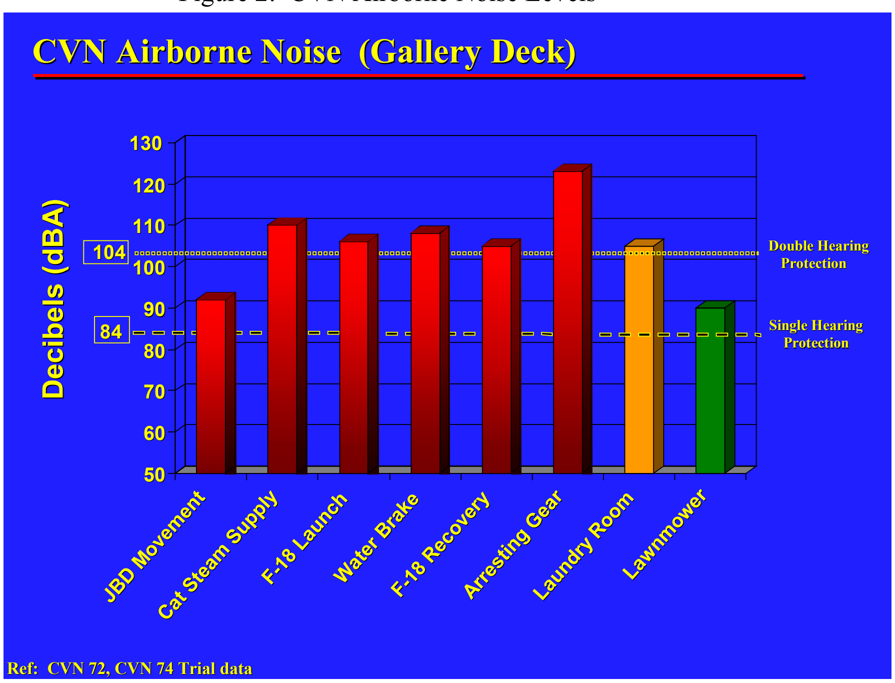
Evaluation of hearing protection use of aircraft carrier decks demonstrated that fully half (47%) of personnel were not using double hearing protection despite noise levels well above the level that even double protection provides (often well in excess of 120 dBA). Use of protective equipment imposes an unrecognized life cycle cost for system support that includes training, medical monitoring, equipment and management overview while providing a variable level of actual protection.

Shipboard Noise Exposures

Noise control is a challenge for both the government and commercial shipbuilding sectors. Certainly in the shipyards, noise is considered an industrial hazard and dealt with accordingly. In a military setting, one can consider the shipboard environment an extension of that industrial setting. The result of that setting is that in 2003, US Navy and Marine Corps veterans receive $153.8 million in hearing disability payments. This has significant implications for military effectiveness, operational readiness and long-term health considerations. The effective noise reduction provided by personnel protective equipment is limited by factors including technology, equipment maintenance and limits of ongoing training and motivation. The growing incidence of military hearing loss despite approximately thirty years of aggressive hearing conservation programs demonstrates the limitations of reliance on protective equipment for management of noise risk. Application of system safety principles and the hierarchy of controls is necessary to effectively manage this risk with a primary focus upon design. Generally, in military applications, noise control is desirable, or even necessary for tactical reasons. In the commercial sector noise control is sought for "comfort". Pursuit of this common goal, with common technology has benefit to the environment as well. Controls must be integrated into systems development and engineering.

Noise levels on aircraft carriers are particularly severe as summarized in Figure 2

Figure 2: CVN Airborne Noise Levels



Supplemental references [4] detail the current trends in military hearing loss, the medical developments related to hearing loss and the current state of personnel hearing protection. (See Proceedings of the 2003 Military Noise Conference http://chppm-www.apgea.army.mil/imnc/Hearing_Conservation/HC_Presentations.html). Ongoing efforts at Institute of Medicine and NIOSH are continuing these studies. The impact on warfighting performance while in a high noise environment is also well known. This information has implications for new ship designs.

Current designs such as HSV 2, X-Craft and LCS will operate at higher speeds. This will result in high noise environment and other challenges in human systems integration. Developments in systems engineering noise control are available to mitigate the noise environment. An overview of the most promising modeling techniques, noise damping techniques and noise control features will be provided. Some of these efforts have been sponsored the Navy's SBIR program. Full application of these techniques has demonstrated to be feasible in most naval designs Identification of noise risk in the system safety process and integration of control measures in the system development process is increasingly practical and essential to ensure protection of personnel and mission.

Enforcing Hearing Conservation Techniques Incentives

For Acquisition Managers, there are short-term incentives based on the ship design/construction being on time and on budget. These short-term incentives tend to run counter to incorporating quiet design practices. To achieve long-term solutions, long-term goals must be chosen with yearly objectives aligned with those goals. Designing a ship to be quiet from the onset sets the tempo for the remainder of the ship's service life. This concept is leveraged from the experiences of the ASW Community as shown in Figure 3 [5]. Certainly, in both Surface Ship and Submarine arenas, the mantra ***Think Quiet*** has produced quiet ARLEIGH BURKE class ships and SEAWOLF submarines, which are the finest applications of US silencing technology. In the arena of construction incentives, the silencing incentive during the DD 963 Class may have produced a lasting mindset of ***Think Quiet*** at the shipyards [5]. Similar incentives could be applied to hearing conservation on new designs and carriers, as well, with marked results.

However, as of this writing, the hearing disability claims are billed to another department. Thus, there is no major incentive to apply design changes. The DOD Hearing Conservation Working Group is sponsoring a research project, conducted by the Naval Undersea Medical Research Lab in Groton CT, to evaluate life cycle costs and risks associated with noise exposure and hearing loss. Additionally, the DOD Environmental Safety and Occupational Process Action Team is working with the USD AT&L and Defense Safety Oversight Committee (DSOC) Acquisition Task Force to provide uniform guidance for life-cycle risk evaluation during program milestone reviews.

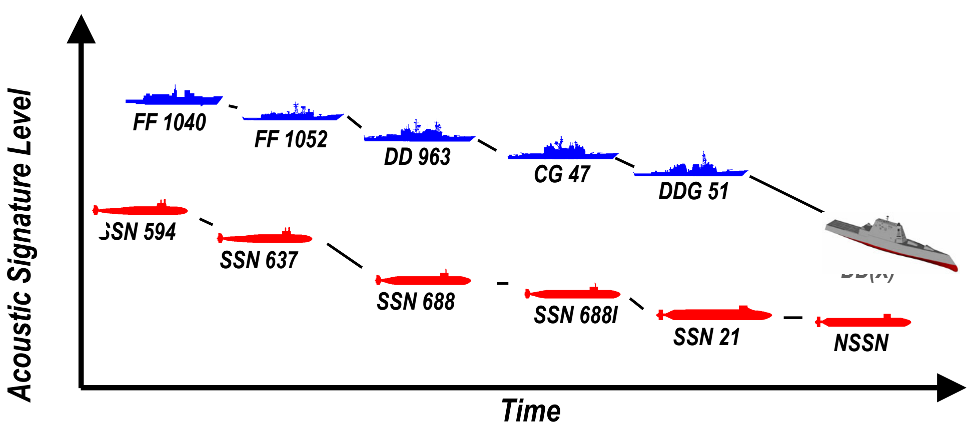


Figure 3. Previous Quieting Investments

Ship Design Criteria and Technical Guidelines

Chief of Naval Operations Habitability criteria [10] are applied to Naval vessels with the general intent of achieving compliance with DOD/Navy noise standards, and providing for relatively quiet areas in berthing and other non-work areas [5]. Slightly more conservative American Society of Testing and Materials (ASTM) [11] and American Bureau of Shipping [12] recommended criteria are also available for consideration, but are not generally used on military vessels.

Design guidelines and criteria are provided by SNAME [13], ASHRAE guidance for heating ventilating and air conditioning design [14], and technical report for HAVAC control prepared by BBN Technologies [15] and reports from several successful noise control projects [5], [16], [17], and [18].

Constraints of weight limit some techniques of mass damping that would typically be applied on shore and in other areas less sensitive to extra weight. Space constraints also create some technical challenges because of the increased velocity and associated noise and turbulence associated with very small duct sizes.

Noise Control Design Alternatives

There are four basic methods to deal with the noise aboard ships (or any other system) [5]:

1. Reduce noise at the source (balance, materials, rotation speed, etc.)
2. Isolate and insulate the noise source from the structure and/or the living/working spaces from the noise source or structure (mufflers, baffles, insulation, etc.)
3. Improve personal hearing protection when the crew must be exposed to a high noise environment such as engine rooms, flight decks, well decks
4. Limit crew exposure to high noise levels (change current mode of operation)

In order to solve the noise issues, a ship wide, complete systems approach integrating all four of these methods where appropriate will be required. However, before the four methods can be applied intelligently, we must clearly identify, quantify, and prioritize the noise interactions and issues. Hence, a complete systems analysis is required.

Systems Top Down Analysis

Approaches to shipboard noise control are highly similar to those of other noise management practice and utilize a sequence of techniques and controls similar to other good engineering practice and the control hierarchy inherent to system safety. Shipboard noise control must be an element of general design and an aspect of the systems engineering process. Retrofits are almost always less cost-effective and sometimes impractical.

The noise sources aboard ships are well known and consist of the usual acoustic culprits: fans, ventilation, pumps, motors, transformers, generators, propellers, water jets, compressors, etc. Assembling these noise sources into any platform such as LCS or an aircraft carrier defines the location and path of each offender. In the design timeframe of Littoral Combat Ship (LCS), noise standards and noise control techniques are readily implemented. With today's noise control technologies, reductions in a ship noise environment are achievable. Unfortunately, compromise and "band aid" fixes are the norm. Today, with a deeper understanding of the impacts of high noise environments, a noise control review is warranted.

Effective ship design does a full system analysis before a course of design action begins. This avoids less-than-successful ship design modification programs that could result in large increases in weight and significant operational impacts. The entire ship should be measured and mapped for noise levels and sources. A CAD based model can be constructed to depict structure, vibrational and acoustical pathways. This process will be dependent on the size and complexity of the subject system. Although many of the noise sources are well known and documented, a systematic modeling effort has not previously been conducted and formally documented. Therefore, this seems to be a logical starting point. In fact this is the incentive in developing JERICHO a design and modeling tool under SBIR Topic N98-092. Information about this program is available at http://www.noise-control.com

Attention to Detail

Because noise is so readily transmitted by undesired pathways, isolation techniques may be readily compromised by minor design and installation deficiencies. Great attention to detail is required to overcome the following potential impediments to control [16]

- Ship arrangements to isolate noise sources from areas requiring quieter environments. This may include acoustic insulation of bulkheads for protection of adjacent areas rather than the space being treated.

- Machinery selection and isolation. Mounting must be selected for appropriate impedance; ideally creating a mismatch that isolates the primary resonator from surrounding surfaces. Piping and ducting and electrical conduits must be carefully isolated and avoid rigid connections to surrounding vibrating surfaces.
- Heating Ventilating and Air Conditioning system should avoid being fitted in without regard to the effect of bends, elbows and branches on creation of turbulence.

Active noise control may be required for certain isolated environmental and condition. Noise cancellation is achieved in geographically constrained locations and requires careful adaptation of configuration, electronics and frequencies amenable to control.

Improved Hearing Protection and Active Noise Control

Advances in electronics and acoustics make active noise cancellation feasible in some constrained situations. Flight line support activities routinely expose personnel to noise levels in excess of attenuation feasible through passive protective equipment. A project is currently underway to update the aviation cranial helmet, which represents 1950s technology unsupported by more recent advances or even general technical and managerial support. Communication headsets, including those with microphones equipped with both active noise cancellation and routine communication are being developed and used for flight crew use. This equipment does not fully address all situations because of limitations in the range of frequency response intrinsic to the technology.

Improved passive noise attenuation is available in many COTS products that should be evaluated for potential fleet use. Inconsistencies in the level of noise reduction provided by national stock items reflect a range of vendor products with widely differing effectiveness. Improved supply selection, management and personnel training is needed to enhance the level of protection provided by commonly used hearing protective devices.

System Safety Risk Acceptance and Noise Exposure

DOD and Navy acquisition regulations [10] and hearing conservation program guidance [8] require application of system safety methodology and risk acceptance at a management level consistent with risk. As noted above, sole reliance on protective equipment provides highly variable attenuation of exposures. Career exposures at level of noise consistent with DOD/NIOSH and ACGIH criteria of 85 dBA (for an eight-hour time-weighted average) create an acknowledged potential for 8% career incidence of hearing loss [1]. Exposure at less protective "OSHA" criteria 90 dBA 8-hour TWA, are nominally inconsistent with DOD criteria. However, these levels of exposure are unfortunately common among military combat and shipboard personnel, and are correlated with a rate of significant hearing loss among 25% of those so exposures [1]. VA data is not well correlated with personnel occupational noise exposures, but shows a general trend consistent with this rate of hearing loss among certain military specialties. See more detailed data presented at the 2001 Military Noise Conference http://chppm-www.apgea.army.mil/imnc/Hearing_Conservation/HC_Presentations.html. Additionally, the 70 hour work-week used for shipboard manpower planning and the lack of quiet times and locations for audiological recovery increase the risk of hearing loss.

In addition to health risk, the immediate threat to mission performance and survivability needs to be considered as in system safety evaluations. An Army evaluation, summarized in the 2001 Military Noise Conference [21] describes the increased risk associated with performance decrement created by noise effects on communication, Table (3)

Table 3 Hearing Loss Degrades Combat Performance - Word Intelligibility

	Good Hearing	***Poor Hearing***
TIME TO IDENTIFY TARGET	40 sec	90 sec
INCORRECT COMMAND HEARD BY GUNNER	1%	37%
CORRECT TARGET IDENTIFICATION	98%	68%
ENEMY TARGETS KILLED	94%	41%
WRONG TARGET SHOT	0%	8%
TANK CREW KILLED BY ENEMY	7%	28%

Source: **Tank Gunner Performance and Hearing Impairment Garinther & Peters, Army RD&A Bulletin 1990, Jan-Feb 1-5)**

Table (4) and (5) summarize the requirements of risk acceptance relative to given level of health hazards.

Table 4. Mishap Risk Assessment Matrix

Probability (Frequency)	Severity				
		I Catastrophic	II Critical	III Marginal	IV Negligible
	Individual System	Dose of a substance or induced stress levels leading to death or a permanent total disabling illness	Dose of a substance or induced stress levels leading to permanent partial disabling illness, and/or ≥ 3 people hospitalized	Dose of a substance or induced stress levels leading to illness with 1 or more lost work days	Dose of a substance or induced stress levels with no lost work time and no job impairment
A Frequent	Frequently, $10^{-1} < P < 1$	IA – 1	IIA – 3	IIIA – 7	IVA – 13
B Probable	Several times, $10^{-3} < P < 10^{-1}$	IB – 2	IIB – 5	IIIB – 9	IVB – 16
C Occasional	Sometimes, $10^{-6} < P < 10^{-3}$	IC – 4	IIC – 6	IIIC – 11	IVC – 18
D Remote	Unlikely, $P < 10^{-6}$	ID – 8	IID – 10	IIID – 14	IVD – 19
E Improbable	Unlikely	IE – 12	IIE - 15	IIIE - 17	IVE - 20

Table 5. Mishap Risk Categories and Mishap Risk Acceptance Levels *

Mishap Risk Index (MRI)	Category	Mishap Risk Waver Authority
1-5	High Risk	Requires Service Acquisition Executive (CAE (ASN-RDA) USSOCOM) Approval.
6-9	Serious Risk	Requires Program Executive Officer (PEO) Approval
10-17	Medium Risk	Requires Program Manager Approval
18-20	Low Risk	Requires Program Manager Review

* (DoDI 5000.2 and SECNAVINST 5000.2C, Derived from Military Standard 882D)

Noise exposures consistent with serious hearing loss or mild hearing loss may be considered in categories of Critical II or Marginal III severity. Given the demonstrated frequency of hearing loss, application of categories of probable (0.01 to 0.001 or occasional 0.001) appears conservative. Combined severity/probability rankings of IIIB and IIC can be derived from these estimates. Therefore it appears reasonable to require PEO approval for the noise levels and associated risk of hearing loss demonstrated among shipboard sailors.

Application of System Safety Principles to Control Noise Hazards in Design of Ships and Facilities:
Application of system safety principles to facility and shipboard confined spaces and elevated work locations provides the following order of precedence for hazard mitigation:

1. Hazard Elimination

2. Noise Barriers and Enclosures

3. Hazard Mitigation via Design

4. Procedures and Warnings: Evaluation of Special Hazard Areas

5. Protective Equipment (and related training and enforcement).

Performance and Economic Incentives

Economic losses associated with hearing loss would be even greater without substantial intervention of hearing conservation programs and some supportive noise control technology. A study has been initiated to evaluate the risks and economic costs of hearing loss associated with military systems provide criteria for consideration of life-cycle costs in the acquisition process [19]. Much of the $3.6 billion dollars in direct costs over the last twenty years, and uncalculated productivity losses, human discomfort and social isolation might have been mitigated by consistent design attention to noise as a risk management factor.

NIOSH [2] (2001) reports that

Through their hearing conservation program, the U.S. Army saved about $504.3 million by reducing hearing loss among combat arms personnel between 1974 and 1994. The Department of Veterans saved $220.8 million and the Army and additional $149 million by reducing civilian hearing loss between 1987 and 1997.

This savings might be markedly enhanced if program managers and designers were provided with stronger and more immediate incentives to control noise and manage life-cycle costs.

Noise must also be considered a performance parameter, sometimes a Key Performance Parameter in Acquisition Capabilities (requirements) Documents and Follow-on contractual documents (RFP, SOO, SOW) and design and performance specifications and test and evaluation requirements. Noise is a general stressor and impairs both quality of life and creates impediments to communication, particularly combat communication. Major re-design of a minesweeper was required to address initial noise levels due to risks of external noise pattern, potential detectibly and concerns for sensititization of mines. The result was a quieter class of vessels, achieved at probable significant initial impacts on costs, schedule and performance. (See Naval Safety Center Success Stories at www.safetycenter.navy.mil/successstories). Key issues must be presented and summarized succinctly at milestone reviews per guidelines of Naval Safety Center Acquisition Safety Website (www.safetycenter.navy.mil/acqusition) to include:

- High noise signature increases operational vulnerability.
- Submarines have consistently been designed with silence as mission-critical. Submarines target other vessels by homing on their noise signatures and vibrations.
- Critical locations for which communication problems could threaten mission performance include aircraft cockpits, combat information centers (CICs), and conference rooms.
- Habitability is an essential element in human systems integration and a parameter of great importance in new acquisition [20].

Additionally, noisy equipment may indicate that there is a problem with how well the machinery is operating. Condition monitoring by noise and vibration measurement has been superceded by techniques such as ultrasonic monitoring. However, noise remains an indicator of equipment function and often a hallmark of design deficiencies such as excessive turbulence in ventilation systems.

Summary

Noise is perhaps the most ubiquitous occupational health hazard in general industry and a particular risk factor in military systems. The cost over two decades for all services has been $3.6B and continues to grow. The unacceptable rate of hearing loss among sailors is characteristic of this DOD wide problem. The continued prevalence of hearing impairment, despite relatively aggressive and often costly hearing conservation programs, reinforces the need to ensure noise control in the design process. Ships are particularly critical for noise control due to prevalence of legacy issues and developing newer technologies such as high-speed vessels. System safety must consider noise in preliminary hazard identification and should integrate noise control approaches into the systems engineering process. Improved technologies for advanced hearing protection are critical, but should not detract from attention to control at the primary sources. Application and enforcement of existing criteria for noise management via the system safety process must be enhanced through education of senior management and system safety practitioners. Basic long-existing noise control engineering practices and newer computational technologies should facilitate noise control.

References:

1. Criteria for a Recommended Standard Occupational Noise Exposure *Revised Criteria 1998* U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention National Institute for Occupational Safety and Health Cincinnati, Ohio June 1998 DHHS (NIOSH) Publication No. 98-126 http://www.cdc.gov/niosh/98-126.html

2. Work Related Hearing Loss 2001 (Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention National Institute for Occupational Safety and Health Cincinnati, Ohio NIOSH) Publication No. 2001-103 http://www.cdc.gov/niosh/2001-103.html

3. American Academy of Audiology Position Statement on Preventing Noise-Induced Occupational Hearing Loss *October 2003* http://www.audiology.org/professional/positions/niohlprevention.pdf

4. Ohlin, Dr. D., U.S. Army Center for Health Promotion and Preventive Medicine, Aberdeen, MD, "Cost of Hearing Loss for All Veterans, 1975 - 1995,"1996

5. K. Yankaskas and R. Fischer X-Craft: Noise Prediction Modeling and Hearing Improvement An HSI Application. To be published American Society of Naval Engineers Proceedings Summer 2005

6. American Conference of Governmental Industrial Hygienists (ACGIH) 2005 Threshold Limit Values for Occupational Exposure to Air Contaminants and Physical Agents and Biological Exposure Indices.

7. Occupational Safety and Health Standards for General Industry 29 CFR 1910 Occupational Safety and Health Standards Subpart: G Occupational Health and Environment Control 1910.95 *Occupational Noise Exposure* (including *Appendix B Methods for estimating the adequacy of hearing protector attenuation*)

8. Department of Defense Instruction DODI 6055.12 DOD HEARING CONSERVATION PROGRAM (HCP) 3/5/2004 http://biotech.law.lsu.edu/blaw/dodd/corres/pdf/i605512_030504/i605512p.pdf

9. Military Standard 882 DOD Standard Practices for System Safety

10. OPNAVINST 9640.1A Shipboard Habitability Program 03 September 1996

11. ASTM F 1166 – 95a (Re-approved 2000) *Standard Practice for Human Engineering Design for Marine Systems, Equipment, and Facilities* American Society for Testing and Materials

12. American Bureau of Shipping Guide for Crew Habitability on Ships December 2001 (available at www.eagle.org)

13. SNAME "Design Guide for Shipboard Airborne Noise Control" (3-37), January 1983.

14. ASHRAE Handbook, "Heating, Ventilating and Air-Conditioning Applications, 1995.

15. L.M. Pettit and B.L. Burkewitz BBN Report No. 7970 Practical Guide for Noise Analysis and Noise Control Design for Shipboard HVAC Systems. Prepared by BBN Systems and Technologies for Kurt Yankaskas, NAVSEA, March 1994.

16. Yankaskas, Kurt and Slotwinski, Thomas, "Acoustic Characteristics of T-AGOS 19 Class SWATH Ships, Naval Engineer Journal, May 1995.

17. G. Schudel, M. Dignan, M. Sutterlin, and D. Hanna, "The Active Control of Airborne Noise in a High Speed Patrol Craft", Noise-Con 94, Ft. Lauderdale FL, May 1994.

18. K. Yankaskas Successful Airborne Noise Control- Attention to Detail Presentation at NOISCON 99 Seattle, Washington 1999

19. P. Weathersby and L. Marshall, L. NSMRL Study Execution Plan Noise Induced Hearing Loss (NIHL) Component of Life-Cycle Costs Presentation to DOD Hearing Conservation Working Group March 2005

20. Department of Defense Instruction DODI 5000.2 Operation of the Defense Acquisition System May 12, 2003 **http://akss.dau.mil/dag/DoD5000.asp?view=document**

21. K Yankaskas Landing on the Roof Presentation to the 2001 Military Noise Conference, Baltimore, MD

Additional Sources of Information

Naval Safety Center Acquisition Safety Website (including section on noise) www.safetycenter.navy.mil/acquisition).

NIOSH Hearing Protective Device Compendium http://www2a.cdc.gov/hp-devices/hp_srchpg01.asp

Industrial Noise Control Manual (PDF)

(356 pages, 9,550K) - NIOSH Publication No. 79-117 (1978) PDF 9550 KB (356 pages) This historic document, originally published in 1975, contains essential information about noise control technology and a collection of 61 case histories of successful noise control projects.

Preventing Occupational Hearing Loss - A Practical Guide

NIOSH Publication No. 96-110 (1996) This document provides guidance in non-technical terms regarding the eight key components of an effective hearing loss prevention program.

Biography:

Kurt Yankaskas is presently the branch head for acquisition in the Human Systems Integration Directorate, Naval Sea Systems Command (NAVSEA 03C). His duties include developing the HSI design standards for LCS. He has 27 years of practical experience and has developed acoustic signature control, design integration, and threat assessment. He was previously a test engineer at CDNSWC where he developed acoustic testing and test procedures and conducted numerous acoustic tests for the fleet.

He earned his B.S. in Ocean Engineering from Florida Atlantic University and his B.S. in Biology from Rensselaer Polytechnic Institute. He received a Meritorious Civilian Service Award for his work on SWATH Acoustic and integrated testing, and was the 1995 recipient of the ASNE Jimmy Hamilton Award.