AUDITORY HAZARD ANALYSIS
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Current Status of Rating Hazard from Intense Sounds and The Need for an Update to MIL-STD-1474(D)

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INTRODUCTION

The problem of rating hazard from intense sounds has for many years remained intractable with the result that current methods work only very poorly. However, hearing science has progressed to the point that accurate prediction is now possible.

In what has come to be referred to as "the Albuquerque studies", the Army Medical Research and Development Command has developed a large data set for protected human exposure to intense impulsive sounds (Patterson and Johnson, 1994). Given this material to work with, the technical community has found that the world's noise standards don't predict the hazard accurately (Chan, Ho, Kan, Stuhmiller and Mayorga, 2001; Price, 2003a; 1987; RTO, 2003). Errors in predicting the onset of unacceptable exposure average almost 10 dB for MIL-STD-1474(D) and errors may exceed 20 dB, depending on the evaluation method and conditions. This lack of accuracy in MIL-STD-1474(D) should perhaps not be too surprising, given that it is based on the science of almost 40 years ago, has essentially no theoretical foundation, and was derived empirically from small arms impulses delivered to unprotected ears (Garinther, Hodge, Chaikin, and Rosenburg, 1975).

The implications of these inaccurate hazard assessments are critical for the operational Army. First, the Health Hazard Assessments (HHAs) for large caliber weapons, based on the current standard, often require the wearing of double hearing protection, a practice that renders the user essentially deaf, and therefore a menace to himself and his companions. Secondly, the HHA may also (incorrectly) prohibit the use of kneeling or prone firing positions with shoulder-launched munitions, the positions, which are normally favored for firer safety in combat. Alternatively, more effective weapons designs may be rejected because the HHA incorrectly rates their hazard. The new, more accurate, technology for hazard assessment must be made available.

THE NEW TECHNOLOGY

The recent advent of the Auditory Hazard Assessment Algorithm for the Human Ear (AHAAH) developed by ARL has resulted in a major change in the scientific sophistication and the accuracy of hazard assessments (ARL, 2003). AHAAH is essentially a theoretically based electro-acoustic analog of the ear designed specifically to predict hazard. It has been developed over many years as part of the basic research program of the Army Research Laboratory (ARL), with the full cognizance of the US Army Medical Research and Development Command and the scientific community. In addition to providing a numerical index of hazard, other technical features of the AHAAH model open the doors to engineering insight which makes it possible to ameliorate hazard and/or the realization of more effective weapons through new designs or the creation of new hearing protective device technologies. In addition, it suggests new weapons deployment and use strategies. These factors produce an ideal moment for a revision of MIL-STD-1474(D).

A historic note. During the 1960's the Army's Human Engineering Laboratory researchers Hodge and Garinther had produced, in conjunction with Coles and Rice in Britain, the research and a proposal that developed into MIL-STD-1474 as a design standard for the noise of Army materiel (CHABA, 1968; Coles, Hodge, Garinther and Rice, 1968). In the early 1970's the Army's Surgeon General adopted it as health hazard criterion (in the absence an alternative).

MIL-STD-1474 was based on the empirical relationship between small arms fire, for unprotected ears, and the onset of temporary shift in threshold sensitivity of the human ear. The rating procedure required comparing a measured peak pressure and duration to a graph. It also assumed the ears would be protected during exposure and allowed an attenuation adjustment for all types of hearing protectors worn singly and a second adjustment for double hearing protection. By the early 1980's it was apparent that it did not assess the hazard from large caliber weapons properly (it tended to over-estimate the hazard). Two NATO RSGs on impulse noise exposure that operated during the 1980s-1990s also confirmed this conclusion (NATO, 1987; 2000).

Creation of the AHAA models. Basic research in hearing loss had also begun in the 1960s at the Human Engineering Laboratory. By the 1980's enough work had been done to establish the requirement for the development of a mathematical model of the human ear's response to intense sound. Building on the basic research, Price and Kalb developed the model first for the cat ear, as representative of mammalian ears (Price and Kalb, 1991) and established its validity (Price, 2003b). The model was then transformed into a model of the human ear by replacing the physical values for the cat ear with those for the analogous structures of the human ear. This version was provided to the NATO RSG participants (Price and Kalb, 1996b) and was validated by comparison to all the available human data (Price, 2003a; Price and Kalb, 1996c).

Furthermore, the AHAAH model was specifically formulated for general use. It runs in essentially real time on PC-based systems and uses Microsoft Windows® conventions in its operation.

Accuracy of the model. The validation with human data showed that the model's prediction of the onset of unacceptable hearing loss (threshold shift > 25 dB in the 95%ile ear) in the human ear was accurate for both protected and unprotected hearing in more than 95% of the cases (more than 70 experiments were analyzable). In comparison, MIL-STD-1474(D) was usable only in cases with protected hearing and was accurate in only 36% of those cases. A-weighted energy, a measured favored by the French (Dancer, 2000), was accurate in about 30% of the cases. Clearly, the AHAAH model is far more accurate than competing methods.

The AHAAH model works as well as it does, in part, because it takes the ear's time dependent, frequency and amplitude non-linearities into account. This is an important point because it means that other systems, which are fundamentally linear in their responses, can't rate hazard accurately over the wide range of amplitudes the ear is exposed to in the military setting. What is needed is a model, such as AHAAH, that is capable of encompassing the technical complexity while still remaining user-friendly.

New analytical capacity. The model includes a feature never before available. The AHAAH model, as part of its analysis, makes a "movie" of the ear's response to the impulse, which allows a review of the calculated effect of different parts of the waveform on the inner ear (which is where the damage occurs). This allows engineering insight into the damage process and can promote the design of safer, more effective weapons, and hearing protective devices that work without interfering with normal sound perception.

ACCEPTANCE OF THE MODEL[1].

In 2001, the US Army Medical Research and Development Command sponsored an independent peer review of the model, which was conducted by a panel convened by the American Institute of Biological Sciences. In the end, the panel recognized the model as superior technology and assented to the following evaluation:

> “The Panel recommends that free-field pressure traces should be input to the model ---------------- and that personnel be allowed to be exposed to combinations of noise that does not result in more than 500 ADUs per day. The Panel feels that it was satisfactorily demonstrated that this limitation would produce 95/95 protection – that is, there is 95% confidence that 95% of the population will experience temporary threshold shift (TTS) that is less than 25 dB. The Panel feels that the process can be applied to all impulse noise conditions, including those whose pressure-time histories appear to be quite different from the ones collected in the Albuquerque study, and still provide the same protection. Finally, the Panel feels that this criterion will provide adequate protection against unacceptable auditory damage over the soldier’s occupational lifetime, as long as the devices are worn and properly fit.”

The AHAAH model has already found a place in the automobile industry. It has served as the basis for a cooperative R&D program with GM on airbag noise and been presented to the engineering staffs of Ford, Chrysler, Audi Porsche, VW, and BMW (Price, 1997a; 1997b; 1997c; 1994; Price and Kalb, 1998). It has achieved formal recognition in this community as the official basis for hazard evaluation of airbag noise within the international Society of Automotive Engineers (SAE, 2003). Within the armaments community, the model has also been presented to the engineering staffs of weapons designers and manufacturers (General Dynamics, Saab-Bofors, Picatinny Arsenal); as well as to meetings of Project Managers of various weapon systems. The engineering community has welcomed the non-arbitrary, physical and scientific basis of the approach.

In other venues, the model has been recognized by being included in an American National Standards Institute draft technical report S3.48TR-200x "Estimation of the hazards posed by exposure to impulse noise".   Within the Army, for a number of years, United States Army Center for Health Promotion and Preventive Medicine (USACHPPM) has included evaluations with the AHAAH model in the HHAs. (Given the unofficial status of the model, these were for information only).

Furthermore, within the larger technical community, the AHAAH model is serving a heuristic value. It has been used by National Institute of Occupational Safety and Health in the analysis of hazard from underground explosions (Price, 2004) and in the analysis of factory noise. And in the SAE, it has been used for the analysis of airbag noise hazard (Price, 2005).

Finally, as this is written, the USACHPPM has been authorized by the US Army Medical Research and Materiel Command to advocate to the Surgeon General (TSG) the adoption of the AHAAH model as the basis for rating hazard for unprotected ears. Presumably, if a medical version of AHAAH is created that allows Hearing Protective Device (HPD) effects to be evaluated also; it would seem likely that such a version could be adopted by TSG for use in HHAs as well.

INTERFACING WITH A NEW DESIGN CRITERION

At a practical level, there is the question as to how the AHAAH model might be used in practice. It appears that there is still a need for a <u>design standard</u> – a document for use by equipment designers that gives them guidance on the safety issues associated with impulse noise. A standard of this type does not deal in the intricacies of HPD design, prescription or use or tactical issues such as weapon use. Such issues are properly left to hearing conservationists or the operational Army. Instead, a design criterion assumes that some moderate attenuation – attenuation achievable in the field --- can be provided by either single or double HPD(s). The standard then becomes a "hurdle" that has to be cleared, which may also provide guidance regarding possible HHA issues. It follows that MIL-STD-1474(D) needs to be upgraded to MIL-STD-1474(E) by replacing the old section on noise hazard with the insertion of the AHAAH algorithm. There does remain a question as to whether or not an improved MIL-STD-

1474 would be used by TSG in performing HHAs. In any case, it is superior to the existing MIL-STD-1474 and it would be available for use, when needed.

In an ideal world, a medical standard would also exist, based on the same AHAAH algorithms. In it, however, issues associated with HPD use could be dealt with, i.e. novel HPD designs, specific HPDs for specific weapons, etc. From the standpoint of the AHAAH model, such a medical standard should be technically achievable.

An upgrade to MIL-STD-1474(E) brings additional issues with it is as well. The acoustic measurement requirements are different – infrasonic frequencies need to be captured because they influence transmission in the middle ear, the dynamic range of measurements needs to be greater while the high-frequency requirements can be relaxed somewhat – and it all needs to be digital. All these requirements can be met with modern technology.

There are new administrative problems associated with the fact that AHAAH is essentially a computer program. If it is to be a standard, then there needs to be some appointed “agent” that maintains the core code and distributes it. This too is not a great technological challenge; but it is an administrative requirement that has not previously existed in quite the same way.

CONCLUSIONS:

1. The present methods for evaluation of impulse noise hazard not accurate.
2. These methods of hazard assessment put our troops at risk and our weapon designers at a disadvantage.
3. The AHAAH model has been developed specifically for the prediction of hazard.
4. It is far more accurate than other methods.
5. It provides important analytical features previously not available.
6. It is written in an easy-to-use format (uses Microsoft Windows® conventions in a PC).
7. It has been developed with the full knowledge of the technical community.
8. It has been peer reviewed and passed the test.
9. It has been peer reviewed and accepted as a standard method by the Society of Automotive Engineers.

10. It appears as a method in ANSI’s draft Technical Report on noise analysis.
11. It is being accepted as a research tool by members of the technical community.
12. MIL-STD-1474 needs to be revised to include the AHAAH model.

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Footnote

[1] USAARL recently published a report [Patterson, J. H. and Ahroon, W. A. (2005) "Evaluation of an auditory hazard model using data from human volunteer studies" USAARL Report No. 2005-01] that held that the AHAAH model was not accurate in its analysis of the Albuquerque dataset. That report has in turn been evaluated [Price, G. R. (2005). "Critical Analysis and Comment on Patterson and Ahroon (2004) "Evaluation of an auditory hazard model using data from human volunteer studies" USAARL Report No. 2005-01", AHATR190805, http://www.arl.army.mil/ARL-Directorates/HRED/AHAAH]. This analysis of Patterson and Ahroon (2005) concluded in part: "----------- In their analysis they repeated failed to apply the model in a manner consistent with its premises and the theory supporting it. Thus the model was not truly tested on its own grounds; but was faulted because it did not conform to their expectations of how the ear would have responded had it behaved according to traditional expectations and been tested under many conditions not actually achieved in the Albuquerque tests (some 65% of the results they used were based on assumed outcomes). The model's results were shown to be accurate, even when counter-intuitive. The accuracy, theoretical sophistication, and analytical power of the model are unmatched by any analytical method currently available."