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A COMPARATIVE STUDY OF HUMAN RESPONSE TO BLAST NOISE AND SONIC BOOMS

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1. INTRODUCTION

Predicting human response to high-energy impulsive sounds such as the sounds generated by sonic booms or explosives remains a difficult problem for which there exist only partial answers. Much research has been undertaken on sonic booms -- most a decade or two ago. More recently, there has been a fair amount of research on blast sounds, notably in the USA [1,2,3], Germany [4], and Australia [5]. In the United States, blast sounds and sonic booms are both assessed in an identical fashion using the C-weighted day-night sound level [6]. Although these two sources are grouped together for assessment purposes, there has never been a single experiment that used these two sources together. (There have been experiments that used simulated or recorded sources but these lack the fidelity to produce the high-level, low-frequency energies and concomitant vibrations and rattles associated with blasts and booms.)

Recently, based primarily on blast noise research, a new method has been proposed for the assessment of high-energy impulsive sound [7]. This new method is based on a large body of research results which shows that (1) a 1 dB increase in CSEL of a blast sound corresponds to about a 2 dB increase in the A-weighted sound exposure level (ASEL) of an equivalently annoying control sound; and (2) groups of test subjects are equally annoyed by a blast sound at a CSEL of 103 dB, a vehicle passby at an ASEL of 103 dB, or band-limited white noise at an SEL of about 104 dB.

The purpose of the study reported herein was to test (1) if subjects responded in a like fashion to both blast and boom sounds and (2) if the response of subjects to sonic booms followed the relations described above. A key factor in the design of this study was the presentation of real blasts and booms to subjects situated in real structures in the field. Like the earlier blast noise research [1,2,3], this study was performed as a paired-comparison test. The control sound used in the previous blast sound research used herein for both the blast and the boom sounds alike.

2. STUDY APPROACH

This study tested human response to sonic booms and blast sounds in one single unified experiment. The study was performed during August 1995 at Naval Air Station (NAS) Fallon, NV. The study site was located in the Nevada desert almost centrally within a 15,000 sq. km. supersonic flying area. Three differing test structures were set up at the test site. One structure was a rehabilitated heavy brick house with a large flat timber beam, wooden roof covered with about 35 cm of small gravel stones. The main room in this house was a 4 m by 6 m living room. The second structure was a rather small, single-room, 3 m by 5 m wood frame building. The third structure was a large mobile office trailer which was divided into two 4 m by 8 m living rooms. Each test room was furnished like a normal living room including couches and chairs, carpets or rugs, coffee and end tables, and window shades, etc. The booms and blasts came from about the same direction and each room had windows which faced the blast site and the direction of arrival of the sonic booms. Each room was cooled using a quiet evaporative air conditioner ducted through muffler sections. The ambient A-weighted sound level in unoccupied rooms was about 40 dB. Two walls of the brick house received the blasts and booms (each at an incidence angle of about 45 degrees), the smaller wall of the wood house directly (90° incidence) received the blasts and booms, and the long wall of the mobile office structure directly received the blasts and booms.

The sonic booms were produced by Navy F-5 fighter aircraft flying at about Mach 1.2, typically at 25,000 to 30,000 ft. above ground level. The blasts were produced by C-4 explosives set off on posts at a height of about 0.9 m. The blast site was located about 900 m from the test houses and, to achieve various blast levels and signatures, 3 sizes of blast charges were used: (1) the big blast which was 2.26 kg of C-4 explosives, (2) the small blast which was 1/4 the size of the large blast or 0.55 kg, and (3) the double blast which was two 1.13 kg charges set off such that the sound from each was separated by about 100 ms in time at the test houses. These double blasts were set off simultaneously but were separated by about 30 m to achieve a 100 ms delay at the test houses. This double blast was created to have a blast sound which somewhat mimicked a sonic boom. The actual sonic boom levels varied naturally because of atmospheric changes and pilot variation from one boom to the next.

Acoustical measurements were made outdoors with a microphone placed close to a wall surface which received the blast and boom waves. In general the outdoor flat-weighted peak sound pressure levels of the booms were about 120 to 135 dB. The corresponding boom C-weighted sound exposure levels (CSEL) were about 26 dB below the flat-weighted peak sound pressure levels. A few boom peak sound pressure levels were higher than 135 dB and many were lower than 120 dB because, even at Mach 1.2, the F-5 aircraft was operating near Mach cutoff. A typical peak, flat-weighted sound pressure level for the big blast was 129 dB and a typical peak level for the small blast was 123 dB. The double blast had a peak level of about 126 dB. For single blasts, the CSEL was about 25 dB below the peak, flat-weighted sound pressure level and for the double blasts, this difference was about 22 dB.

The test was performed using the paired-comparison study methodology. Subjects listened to pairs of sounds. One sound in the pair was a blast or boom test sound. The other sound (control sound) in the pair was a 0.5 second long band limited white noise burst presented to the subjects via loudspeakers placed in each living room. The blast or boom test sound was randomly presented first or second in each pair of sounds.

The control sounds and test methodology was very similar to that used in previous blast noise research [1,2,3]. Microphones located near the subjects at ear level recorded the indoor test and control signal levels. The primary measure used was the blast sound C-weighted sound exposure level and the control sound A-weighted sound exposure level. The control sounds were adjusted such that at low control sound levels, nearly all of the subjects would find the test sound more annoying and at high control sound levels, nearly all of the subjects would find the control sound more annoying. In between was the point where 50 percent of the subjects found the test sound to be more annoying and 50 percent found the control sound to be more annoying. This was the equivalency point, the point where the annoyance generated by the blast or boom equaled the annoyance generated by the control sound.

To perform the analysis, the blast and boom signals were divided into 4 dB wide bins. The bin center was used to designate the blast or boom level. The data in any bin contained many control levels so it was possible to plot the percent finding the test signal more annoying as a function of the control signal level. For each such bin, the data were plotted and a transition function was fit to the data using a commercial, PC, curve fitting software package. The 50 percent point was found for each such curve. This is the equivalency point, the point where the annoyance generated by the control signal is equivalent to the annoyance generated by that blast or boom signal.

3. ANALYSIS AND DISCUSSION

Analysis was performed by plotting the pairs of equivalency points developed from the bin of data. The starting point for the analysis was Figure 1 which is based on results in Ref. [7]. This figure compares the indoor measured blast sound CSEL with equivalently annoying white-noise control sound ASEL. Figure 1 includes the earlier overall blast noise results from Munster and Grafenwöhr Training Area (GTA), Germany and Aberdeen Proving Ground, MD, USA. The new data are generally similar to the older blast noise data but there is quite a bit of scatter to the data.

It is not clear that C-weighted sound exposure levels should be measured indoors near to the subjects. All environmental noise is normally measured or predicted outdoors. Further, in the case of high-energy impulsive sounds, the C-weighting was not chosen for its ability to directly correlate with human response. Rather, the C-weighting was chosen primarily to use a standardized measure which incorporated the low-frequency sound pressures associated with high-energy impulses, the energies which contribute to building vibrations and rattles. This is the outdoor measured CSEL, not the CSEL measured near the subjects ears. Therefore, the old data from Figure 1 were converted to portray the results with outdoor-measured CSEL. These converted data are used in Figure 2.

Figure 2 shows outdoor measured CSEL as a function of indoor-measured, equivalently annoying white noise control sound ASEL. (The indoor measured control sound levels are used because there were no corresponding outdoor measured levels for sounds created by indoor-located loudspeakers.) For NAS Fallon, all of the subject data were reanalyzed using actual outdoor CSEL measurements. Again the data were combined into bins. For the older blast noise data, the outdoor-measured CSEL were approximated as the indoor-measured CSEL plus a constant. For APG, the original outdoor and indoor measured data were used to find a constant difference of 14 dB with a standard deviation of less than 1 dB; for Munster, the original data were used to find a constant difference of 12 dB, again with a standard deviation of less than 1 dB, and for the earlier Grafenwöhr data (where the original data are no longer readily available), an average value of 13 dB was used.

The results in Figure 2 show much greater consistency than do the results in Figure 1. This tends to reinforce the concept that C-weighted is a useful **outdoor** measure for assessing the indoor community response to high-energy impulsive sounds. Figure 2 shows that in the house and mobile office, the annoyance was greater to sonic booms than to blasts at the same CSEL level. The boom level should be about 5 dB below the blast level for equal annoyance. In the wooden house, the responses to both blasts and booms were equal.

In general the NAS Fallon data fit the wider body of blast data fairly well. The blast data from Fallon typically lie about 1 or so dB above (less annoying) the regression line fit to the older blast sound data and the sonic boom data typically lie about 3 dB below (more annoying) this regression line. The discrepancy between the blast and boom data may indicate that C-weighting is not an ideal measure for high-energy impulsive sounds. The booms had much more low-frequency energy that did the blasts. Therefore, a weighting that would cut off at a lower frequency than 20 Hz (including more of the energies which cause a building to vibrate) would cause these data sets to better align. A preliminary analysis shows that with a 5 Hz cut off, the boom and blast annoyance curves for the house and mobile office align with one another, respectively.

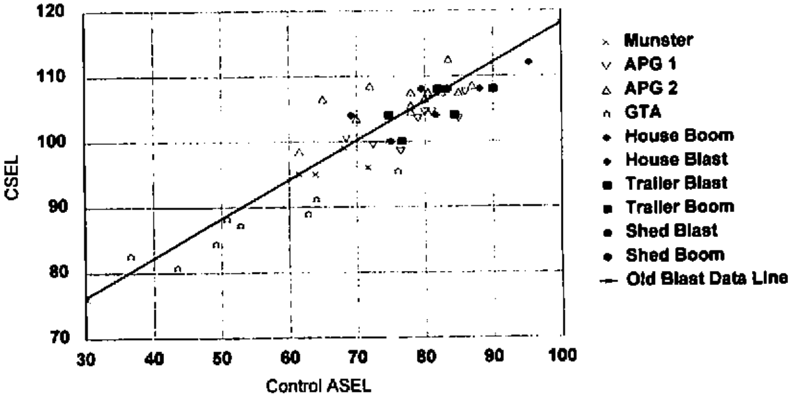

Figure 1. Data and regression line for C-weighted sound exposure level of blast or boom sounds versus A-weighted sound exposure level of equivalently annoying control sound. Blast and booms measured **indoors**; control sound measured indoors.

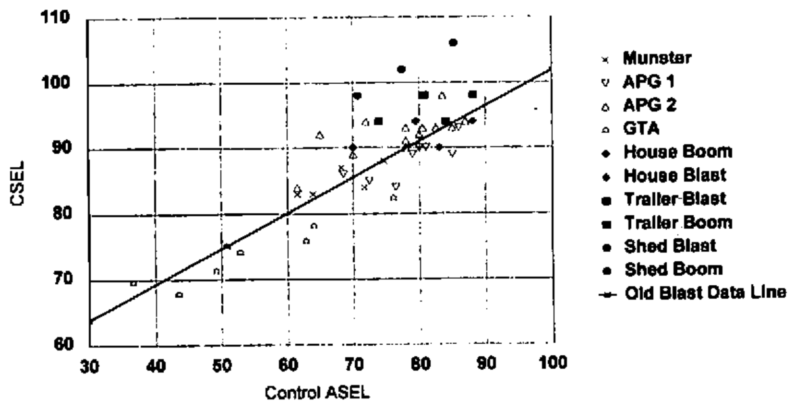

Figure 2. Data and regression line for C-weighted sound exposure level of blast or boom sounds versus A-weighted sound exposure level of equivalently annoying control sound. Blast and booms measured **outdoors**; control sound measured indoors.

4. CONCLUSIONS

The results show that only the outdoor-measured CSEL should be used to predict human and community response. It is inferred that the outdoor measured CSELs work because they contain more of the energies which cause building vibrations and rattles.

The difference between blast and boom sound responses offers one indication that a weighting with a lower cut off than 20 Hz (C-weighted) should be used to assess high-energy impulsive sounds.

The general results show that the human response to sonic booms is similar to their response to blast sounds. There is some indication that response to booms is greater than response to blasts. However, all of the brick house and mobile office data fit the wider body of blast data quite well, so regression curves to this wider body of data provide a good overall empirical high-energy impulsive noise assessment tool.

The results in this study certainly support the earlier result that a 1 dB increase in CSEL of a blast sound corresponds to about a 2 dB increase in the A-weighted sound exposure level (ASEL) of an equivalently annoying control sound

5. REFERENCES

[1] Schomer, Paul D., Edmund Buchta, and Karl-Wilhelm Hirsch **(1991).** "Decibel annoyance reduction of low-frequency blast attenuating windows," *J. Acoust. Soc. Am.*, **89**(4), 1708-1713 (April 1991).

[2] Schomer, Paul D., *et. al.*, **(Mar 1994).** "Human and community response to military sounds: Results from field-laboratory tests of small arms, tracked-vehicle, and blast sounds," *Noise Con. Eng. J.*, **42**(2), 71-84, Mar-Apr 1994.

[3] Schomer, Paul D., and L. Ray Wagner **(1995).** "Human and community response to military sounds – Part 2: Results from field-laboratory tests of small arms, 25-mm cannons, helicopters, and blasts," *Noise Con. Eng. J.*, **43**(1), 1-13, Jan-Feb 1995.

[4] Buchta, Edmund, **(1989).** *Pilotprojekt für passive Schallschutzmass-nahmen am Truppenübungsplatz Grafenwöhr,* Bundesminister der Finanzen (Federal Ministry of Finance), (Bonn, 1989).

[5] Cook, R. *et. al.*, **(1994).** "A Criterion for Community Response to Impulse Noise from Large Calibre Weapons and Explosions," Commissioned Report No. 79, National Acoustic Lab., Chatswood NSW 2067 Australia, 1994.

[6] ANSI, **(1986).** *"AMERICAN NATIONAL STANDARD Method for Assessment of High-Energy Impulsive Sounds with Respect to Residential Communities,"* ANSI S12.4-1986, (Acoust. Soc. of Am., New York, 1986).

[7] Schomer, Paul D., **(Nov 1994).** "New descriptor for high-energy impulsive sounds," *Noise Con. Eng. J.*, **42**(5), 179-191, Nov-Dec 1994.

6. ACKNOWLEGEMENT

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