ACOUSTICAL CHARACTERISTICS OF GUNS AS IMPULSE SOURCES

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SUMMARY

The acoustical characteristics of five guns, including three calibres and two gun types, were measured to determine their suitability as impulse sources. Comparisons were made with spark and loudspeaker impulse sources. One 0.38 calibre revolver was found to be a suitably repeatable, omni-directional impulse source providing adequate sound energy in the octave bands from 125 to 5000 Hz.

SOMMAIRE

Les caractéristiques acoustiques de cinq pistolets, y compris trois calibres différent et deux modèles différent, ont été mesurées pour déterminer leur aptitude à agir comme source d'impulsions. Des comparaisons ont été effectuées avec l'étincelle et le haut-parleur comme sources d'impulsions. Un révolver de calibre .38 s'est avéré être une source d'impulsions omnidirectionnelle, sufisament reproductible, assurant une énergie sonore adéquate dans les bandes de fréquences 125-5000 Hz.

INTRODUCTION

Impulsive sources are frequently required in both architectural and building acoustics measurements. For many years various guns have been used as impulse sources, usually to obtain reverberation times or to examine the details of reflection sequences in a room. They are potentially useful as a sound source to measure newer acoustical measures such as early-to-late arriving sound ratios, and can also be used to measure the sound transmission loss of walls.[1] Some authors have criticized the use of guns as impulse sources, suggesting that they are not adequately repeatable.[2,3] There is little published information describing the acoustical characteristics of guns. This report is intended to provide some details of their acoustical characteristics so that others can more satisfactorily decide on the suitability of this potentially very convenient impulsive source.

In this report, the characteristics of five guns are compared, including three calibres and two types of guns. The second section of the report compares the characteristics of the guns to those of sparks and loudspeakers.

CHARACTERISTICS OF AN IDEAL IMPULSE SOURCE

There are a number of practical and acoustical characteristics of an ideal acoustical impulse source. As most measurements are made in the field, it is desireable that the source be portable and therefore light-weight. Acoustically the source should be omni-directional and should have a smooth if not flat, broad frequency response spectrum. In addition the source must provide a large signal-to-noise ratio, and be repeatable. Room acoustic measurements are typically made in standard octave bands from 125 to 8000 Hz. Thus the source must produce significant energy over this entire frequency range, so that it is possible to obtain a minimum of 30 or 40 dB of decay before the background noise level is reached in each octave band. It is desirable that the source have at least a smooth spectrum so that results can later be corrected for the non-uniform source frequency response spectrum. The requirement for a broad source spectrum normally coincides with having a very short duration impulse that would permit the identification of individual reflections. Some lack of repeatability can be overcome by averaging the responses to several pulses, but measures such as reverberation times and early-to-late sound ratios are reasonably independent of small variations in the source pulse. The directionality of the source is critical for comparison with both other measurements and calculations involving a point source because it is not possible to correct for directional source effects after measurements have been made.

Mathematically the impulse response of a linear system is exactly equivalent to the steady state response of the same system and completely describes the response between two points. Such an impulse response can be obtained directly using an impulsive source or can be calculated from the steady state transfer function between the two points.[3,4] This latter approach requires considerable additional signal processing calculations to produce the long impulse responses required in rooms and is not considered in this report. To directly produce impulse responses commonly used sources have included: guns, sparks, exploding balloons, and loudspeakers.

ACOUSTICAL CHARACTERISTICS OF GUNS

The guns tested in this study are shown in Figure 1, and included 0.22 and 0.32 calibre starter's pistols, a 0.32 calibre H & R (Harrington and Richardson) starter's revolver, and two 0.38 calibre Smith and Wesson revolvers (#1 and #2). The 0.38 calibre revolvers were modified so that the barrel was plugged and a wedge shaped piece was placed in front of the shortened cylinder. The 0.32 calibre H & R starter's revolver was of a similar construction to the modified 0.38 calibre guns. On the 0.22 and 0.32 calibre starter's pistols the exploding charge exited freely upwards from the gun and did not encounter wedges or other objects that would deflect the blast.

The gun shots were tape recorded in an anechoic room using a 1/4-inch Bruel & Kjaer condenser microphone and a Technics digital tape recorder. Each gun was recorded at a distance of 2 m and at incident angles of 0 to 180 degrees in 45 degree steps in both the horizontal and vertical planes, and four repeats were recorded for each condition after some experimentation with greater numbers of shots. Zero degrees corresponded to the gun pointing at the microphone. The recorded shots were digitized and processed by computer using a Fast Fourier Transform procedure to synthesize comparable octave band results for each gun. The 0.38 calibre guns fired black powder blanks made by Dynamit Nobel while the other guns fired smokeless Remington blanks.

Figure 2 compares octave spectra for three gun calibres for a 0 degree angle of incidence (that is the gun was pointing at the microphone). The 0.32 calibre gun has a similar spectrum shape to the 0.22 calibre gun but with greater sound energy in each octave. The 0.38 calibre gun (#1) has a much flatter spectrum with relatively much more low frequency energy than the other guns. (0.38 calibre gun results refer to the #1 gun unless the #2 gun is specified). The flatter spectrum of the 0.38 calibre gun is probably due to both the larger charge of the 0.38 calibre blank and to the slower burning black powder that was used in the blank cartridges for this gun. Although the smaller calibre guns lack sufficient energy in the lowest band (125 Hz), the 0.38

calibre gun results indicate that there is satisfactory acoustical energy in all seven octave bands.

Figure 1. Photographs of the guns: (a) 0.22 and 0.32 starter's pistols; (b) 0.32 calibre H & R revolver; (c) 0.38 calibre revolver #1; (d) 0.38 calibre revolver #2.

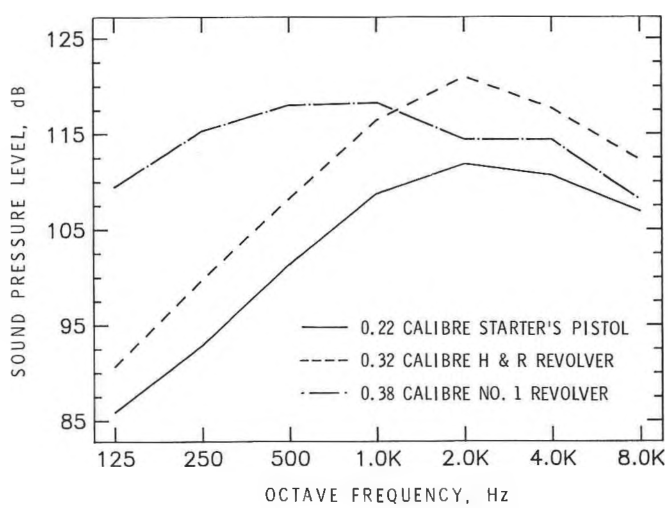

Figure 2. Octave band spectra of guns at 0 degrees incidence.

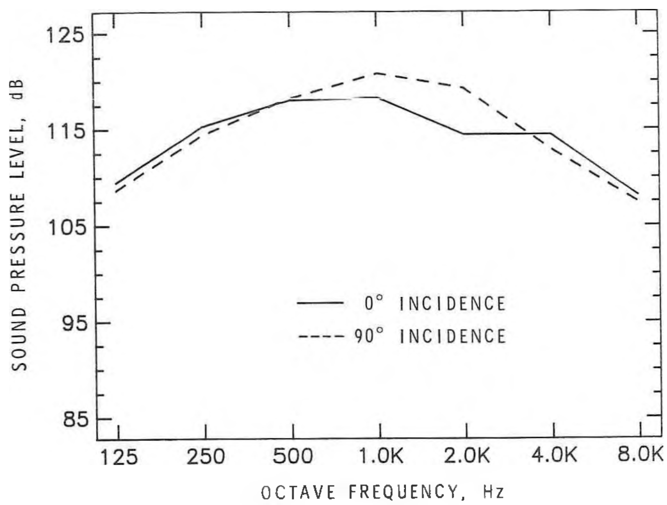

Figure 3. Octave band spectra of 0.38 calibre No. 1 revolver in horizontal plane.

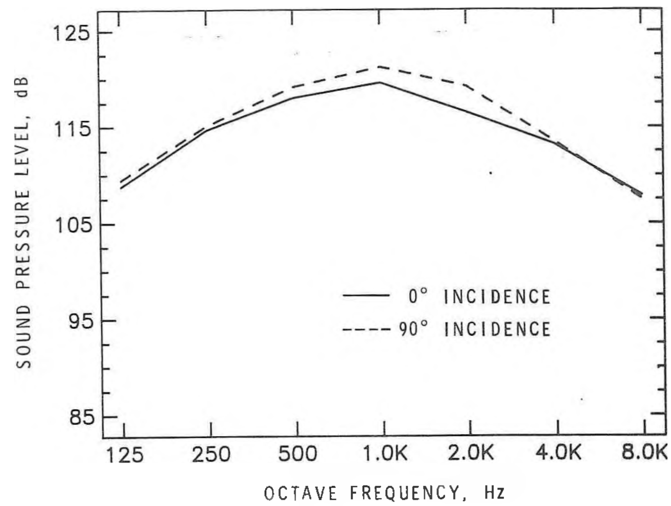

Figure 4. Octave band spectra of 0.38 calibre No. 1 revolver in vertical plane.

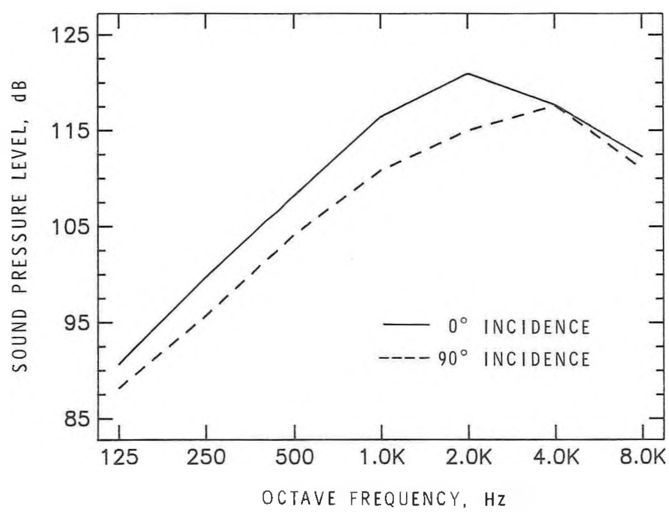

Figure 5. Octave band spectra of 0.32 calibre H & R revolver in the horizontal plane.

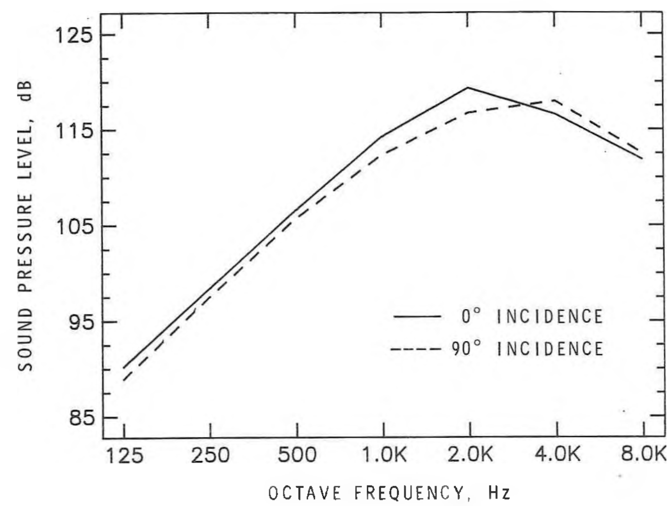

Figure 6. Octave band spectra of 0.32 calibre H & R revolver in the vertical plane.

Figures 3 and 4 show octave band spectra for the 0.38 calibre gun at 0 and 90 degree angles of incidence in the horizontal and vertical (with the gun pointing up) planes respectively. For these angles of incidence, the resulting sound levels are quite independent of angle except for small changes at 1000 and 2000 Hz. Figures 5 and 6 give similar results for the 0.32 calibre H & R gun. Figure 5 shows that for this gun sound levels for frequencies from 125 to 2000 Hz are all lower for the 90 degree incidence case than for the 0 degree case. Thus at intermediate and lower frequencies more energy is projected forward than to the side when this gun is aimed horizontally. In the vertical plane the gun is quite omni-directional.

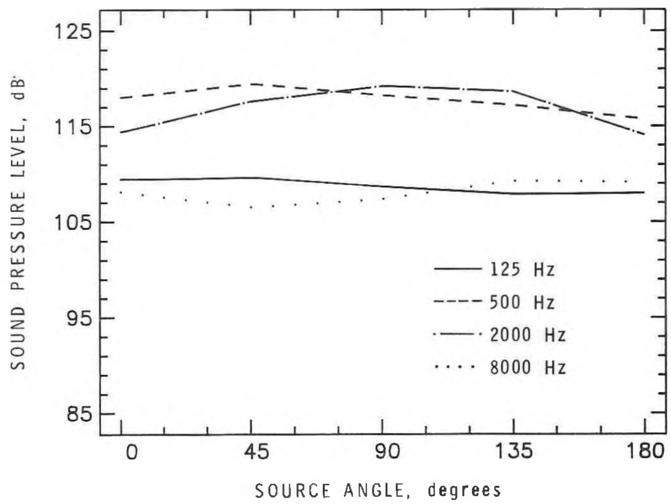

Figure 7. Octave band sound levels versus angle in the horizontal plane for the 0.38 calibre No. 1 revolver.

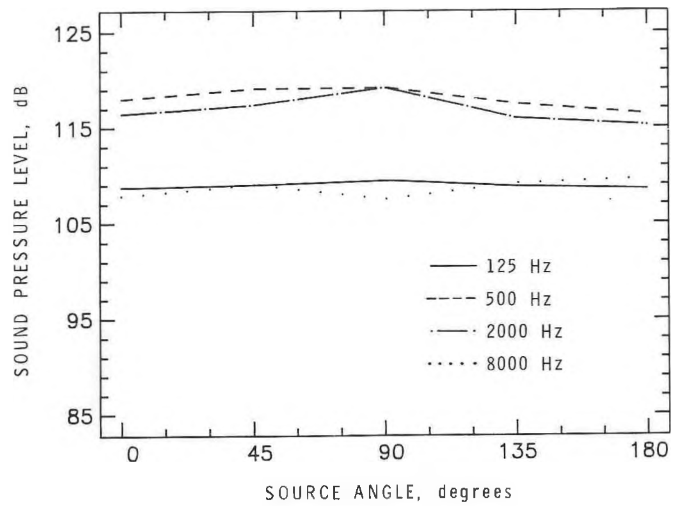

Figure 8. Octave band spectra levels versus angle in the vertical plane for the 0.38 calibre No. 1 revolver.

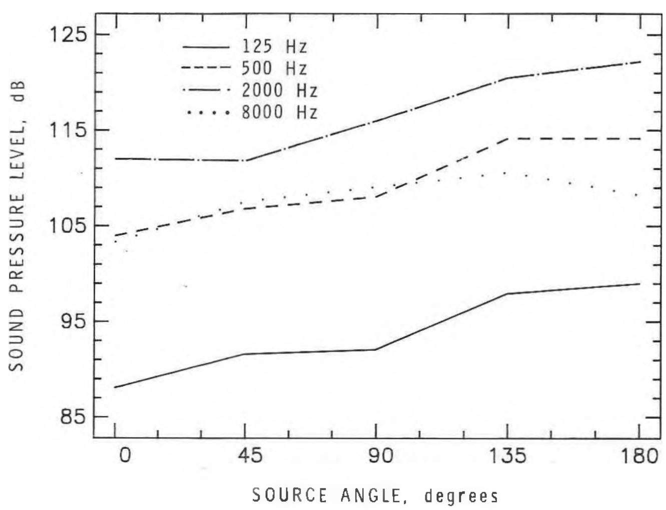

Figure 9. Octave band sound levels versus angle in the vertical plane for the 0.32 calibre starter's pistol.

Figures 7 and 8 give more complete directional information for the 0.38 calibre gun in four of the seven octave bands. These results again show that this gun is a reasonably omni-directional source at all frequencies tested. There is only a small tendency to radiate a little more strongly to the side at 1000 and 2000 Hz. The degree of omni-directionality at 8000 Hz is quite remarkable and would not be possible with other commonly used sources such as loudspeakers. The directional properties of the 0.22 and 0.32 calibre starter's pistols when rotated in the vertical plane (gun pointing up) were characteristically different. Figure 9 shows the variation in four octave bands in the vertical plane for the 0.32 calibre starter's pistol. When the gun was positioned at 180 degrees the opening in the top of the gun was pointing directly at the microphone and levels in all bands were clearly higher. Even though it was very small, this type of explosive source emitting into free space is directional and particularly so at the lowest octave band measured. This characteristic directionality indicates that one would prefer not to use this type of gun as an acoustical source, and also helps to explain the directional properties of the other guns.

Table I summarizes the directional properties of all five guns. For each gun the range of measured sound levels is given over the ten different directional measurements in each octave band. Thus for the 0.22 calibre gun at 125 Hz the difference between the lowest and highest sound levels measured over all ten different angles of incidence was 10.3 dB. The 0.22 and 0.32 calibre starter's pistols have ranges as large as about 11 dB mostly due to the directional properties of these guns in the vertical plane. The 0.38 calibre gun (#1) has ranges from 1.8 to 5.2 dB and is thus the least directional of the five guns. In the 125 and 4000 Hz octave bands it is omni-directional within less than 1 dB and in the worst case (2000 Hz) within ±2.6 dB.

TABLE I

Maximum Range of Measured Octave Band Levels Over All Angles

Octave	0.22 Calibre Pistol	0.32 Calibre Pistol	0.32 Calibre Revolver	0.38 Calibre #1 Revolver	0.38 Calibre #2 Revolver
125	10.3	10.9	4.1	1.8	5.4
250	10.4	9.8	4.2	2.5	5.0
500	11.5	10.2	4.6	3.7	4.9
1000	10.7	9.2	5.7	4.7	5.7
2000	9.5	10.4	6.1	5.2	6.4
4000	5.6	7.9	5.3	1.9	2.0
8000	7.5	7.3	3.1	3.1	2.2

It remains to explain the increased directionality of the very similar 0.38 calibre gun (#2) and the 0.32 H & R gun. From the 0.22 and 0.32 calibre starter's pistol results an explosive source emitting into free space was quite directional at intermediate and low frequencies. On the other guns the explosion is deflected by wedge-shaped pieces. This wedge was quite blunt and only 0.5 cm long on the 0.38 calibre (#1) gun but 1.5 cm or longer on the other 0.38 calibre gun and on the 0.32 calibre gun. It seems that the shorter blunter wedge more effectively deflects the forward-going acoustic energy to the side. Accordingly the second 0.38 calibre gun and the 0.32 calibre H & R gun are more directional when rotated in a horizontal plane.

For each set of four shots the mean sound level was calculated and the standard error of the mean was calculated in each octave band. As these standard errors varied unsystematically with varied orientation of the gun and the octave band, only the overall mean of the standard errors along with the minimum and maximum for each gun are given in Table II. The 0.38 calibre guns were similar and more satisfactory with the smaller standard errors, indicating that most of the time the mean octave band results would repeat within less than ±0.5 dB and in the worst cases within less than ±1 dB. The similarity between the two 0.38 calibre guns and between the two 0.32 calibre guns suggests that this repeatability is largely a function of the blank cartridges used. The 0.22 calibre gun was the most variable with a mean standard error of 0.7 dB. There is a trend for smaller calibre blank cartridges to lead to greater variablity.

TABLE II

Mean, Minimum, and Maximum Standard Error of Measured Octave Band Sound Levels for Sets of Four Shots

	0.22 Calibre Pistol	0.32 Calibre Pistol	0.32 Calibre Revolver	0.38 Calibre #1 Revolver	0.38 Calibre #2 Revolver
Minimum	0.25	0.0	0.08	0.13	0.13
Mean	0.68	0.44	0.46	0.37	0.37
Maximum	1.41	1.68	0.92	0.89	0.75

COMPARISONS WITH OTHER SOURCES

High voltage spark sources are also commonly used to create acoustical impulses. Figure 10 compares the octave spectrum of the 0.38 calibre gun with a typical spark source from Reference 2. Although the spark spectrum is quite broad, the energy is centred at 4000 Hz and there is not enough energy in the 125 Hz octave band. Some simple experiments using a borrowed high voltage source indicated that a spark source was generally quite omni-directional and that the repeatability was similar to the 0.38 calibre gun. The high voltage sources required to produce sparks are usually quite heavy and certainly not as portable as a small gun. The spark source is thus seen to be less satisfactory for architectural acoustic measurements because it lacks sufficient low frequency energy, it is not as portable, and there is added danger and inconvenience associated with the high voltage supply. The directionality and repeatability of the spark source is generally similar to that of the 0.38 calibre gun, and it may be quite useful in acoustical models where higher frequency energy is required.

Loudspeakers are also frequently used to produce impulses in rooms. In some cases measurements are made over a limited frequency range[5] where the response of the loudspeaker is adequately flat and omni-directional; in other cases[6] specially shaped pulses are fed to the loudspeaker that have been adjusted to compensate for the non-flat response of the loudspeaker. Unfortunately the directional characteristics of the loudspeaker are frequently ignored. Figure 11 plots the radiated sound level

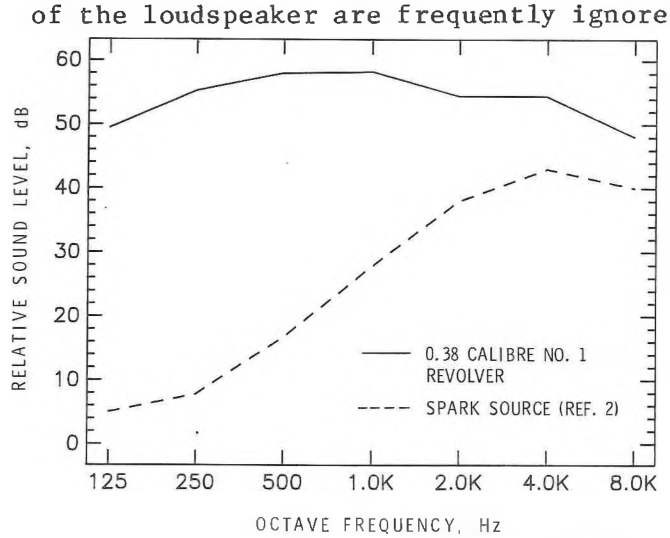

Figure 10. Comparison of octave band gun and spark source.

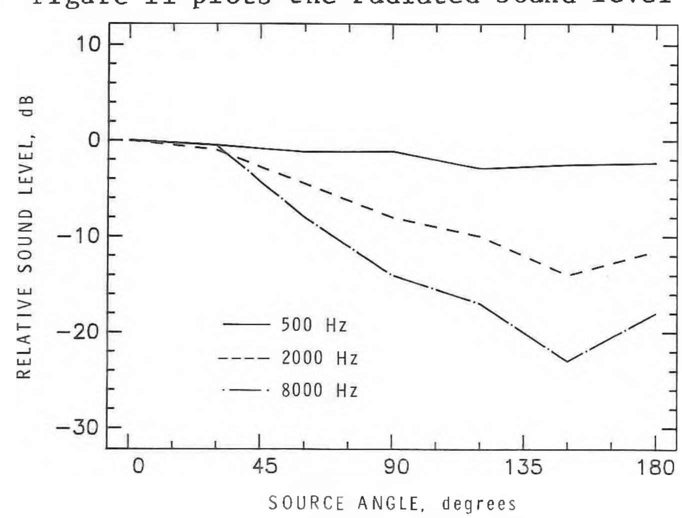

Figure 11. Octave band sound levels versus angle for a small loudspeaker.

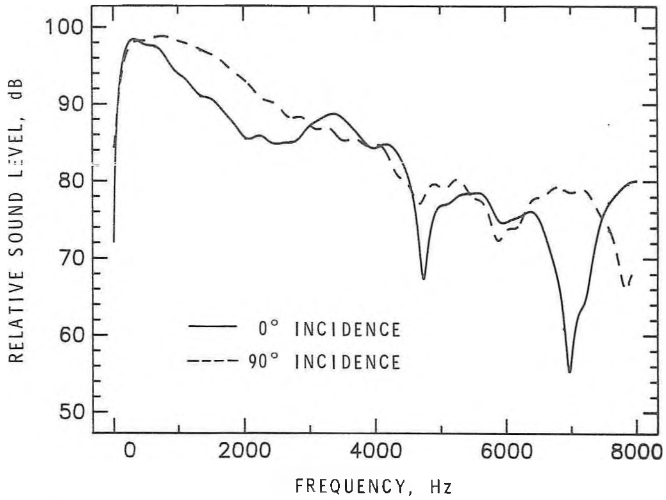

Figure 12. Narrow band power spectrum of 0.38 calibre No. 1 revolver.

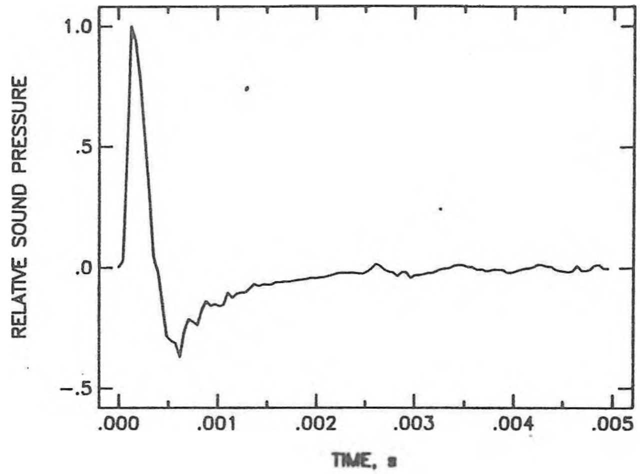

Figure 13. Anechoic time history of 0.38 calibre gun.

versus angle at three different frequencies for a small PSB Alpha-II loudspeaker. (This loudspeaker contains a 9 cm and a 2.5 cm diameter driver in a box that is approximately 12 by 22.5 by 12.5 cm). Because of its small size this loudspeaker is quite omni-directional at 500 Hz, but even at 2000 Hz it is more directional than the 0.38 calibre gun shown in Figures 7 and 8. At higher frequencies the loudspeaker becomes more directional until at 8000 Hz the radiated sound level varies by up to 23 dB with varied angle. At the same time this loudspeaker is not large enough to radiate adequate energy in the 125 Hz octave band. Although high quality loudspeakers are designed to have a flat frequency response at particular angles, the higher frequency response usually becomes quite irregular in detail. Figure 12 shows narrow band spectra of the 0.38 calibre gun for 0 and 90 degrees incidence. The spectra are quite smooth up to well in excess of 4000 Hz and so it is readily possible to correct for the non-uniform frequency response of the gun should this be necessary. In a number of ways loudspeakers are inferior to guns as acoustical impulse sources. Although they offer more precise repeatability, they and the associated electronics are much less portable. There seems to be no one loudspeaker that is small enough to be adequately omni-directional yet capable of radiating adequate power at lower frequencies. One can, at some cost, attempt to correct for the non-uniform response of a loudspeaker at one particular angle but it is not possible to correct for the very directional properties of loudspeakers.

It is sometimes of interest to have details of the time history of the source pulses, such as when attempting to identify individual reflections. Figure 13 gives an example anechoic response of the 0.38 calibre gun showing that the first zero crossing occurs after approximately 0.32 msec. The 0.32 calibre guns had shorter pulses of approximately 0.13 msec duration while the 0.22 calibre gun produced an approximately 0.18 msec pulse duration. Sparks may produce even shorter pulses which might be an advantage in some situations, but this will necessarily be associated with relatively less low frequency energy. Loudspeakers could only produce such short duration signals if the signal is first modified in a complicated manner to correct for the speaker response in some direction.[6,7]

CONCLUSIONS

Comparisons of the acoustical characteristics of a number of guns showed that a 0.38 calibre gun firing black powder blank cartridges is a suitable source of acoustical impulses. The gun was easily portable, and a repeatable, reasonably omni-directional source, radiating sufficient acoustical energy in all octave bands from 125 to 8000 Hz. It was further shown that not all guns were as satisfactory. In particular, the details of the wedge in front of the firing chamber influenced the directional properties of the gun. The smaller calibre guns tested did not provide adequate low frequency sound energy, and repeated a little less accurately.

Comparisons with spark and loudspeaker sources indicated that they were less satisfactory impulse sources. Spark sources tend to be lacking in low frequency sound energy, and involve bulky and potentially dangerous high voltage supplies. Spark sources appear to have somewhat similar directional properties and repeatability to the 0.38 calibre gun. Loudspeakers are more precisely repeatable, but again are bulky and hence much less portable. Loudspeakers usually have irregular frequency response characteristics that vary considerably with direction. It appears impossible to have a single loudspeaker that is satisfactorily omni-directional over a sufficiently broad frequency range.

Overall the 0.38 calibre gun was the most suitable source for measurements requiring acoustical impulses in rooms. Such a gun is a practical solution to the need to provide a single, omni-directional impulse from which decay times and early-to-late arriving sound ratios can be derived in octave bands from 125 to 8000 Hz.

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REFERENCES

1. "Airborne Isolation Measurements by Impulse Technique." J. Roland. Noise Control Engineering, Vol. 16, No. 1, p. 6-14 (1981).
2. "The Signal-to-Noise Ratio for Speech Intelligibility - An Auditorium Acoustics Design Index." H.G. Latham. Applied Acoustics, Vol. 12, No. 4, p. 253-320 (1979).
3. "A New Method to Acquire Impulse Responses in Concert Halls." A.J. Berkhout, D. deVries and M.M. Boone. J. Acoust. Soc. America, Vol. 68, No. 1, p. 179-183 (1980).
4. "An Efficient Algorithm for Measuring the Impulse Response Using Pseudorandom Noise." J. Borish and J.B. Angell. J. Audio Eng. Soc., Vol. 31, No. 7, p. 478-488 (1983).
5. "Impulse Testing Techniques for Auditoria." M. Barron. Applied Acoustics, Vol. 17, No. 3, p. 165-181 (1984).
6. "The Generation of Short Duration Acoustic Signals." J.C. Davies, J. McIntosh and K.A. Mulholland. J. Sound and Vibr., Vol. 76, No. 1, p. 77-82 (1981).
7. "Generation of Desired Signals from Acoustic Drivers." R. Ramakrishnan, M. Salikuddin and K.K. Ahuja. J. Sound and Vibr., Vol. 85, No. 2, p. 39-51 (1982).