

ESTIMATION OF ACOUSTICAL SOURCE STRENGTH OF MUZZLE BLASTS ON THE BASIS OF LAUNCH SPEED AND BULLET WEIGHT

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INTRODUCTION

ISO/TC43/SC1/WG51 is currently discussing propagation models for shooting sounds for prediction of annoyance. It is well understood, in this working group, that at least the octave spectrum is needed at the source to calculate the propagation of shooting sounds with respect to shielding and air absorption and other frequency-dependent phenomena.

The muzzle blast from a gun is a highly directional acoustical source. A difference in level of 15 dB between the radiation in the direction of fire and to the rear is not unusual. In addition, the spectrum changes with direction. Therefore, a good estimation of frequency and angle dependent source data is required as the basis of any reliable prediction of noise load in the vicinity of shooting ranges. However, such detailed emission data for the existing huge variety of military and civil weapons, ammunition and demolition devices are not available and will never be, in terms of reliably measured data. In an ammunition guide for instance, one can find 52 ammunition types for the Winchester .308 calibre, being different with respect to mass of propellant by 2.2 g to 3.2 g and with bullet energy ranging from 2.6 kJ to 3.6 kJ. The gun itself will influence directivity through barrel length and muzzle brake for example.

On the other hand, the prediction of shooting noise needs data on the activity at the installation. With respect to the detailed features of ammunition and weapon, it is unlikely that such important input data will be recorded for every round fired. It is more likely that the input data will read 'X of rounds on range A with Winchester .308'. Hence, there is a need for an engineering rule to estimate such data even from poor information, e.g. the kinetic energy of the bullet.

ESTIMATION METHOD

The proposed method splits up into two parts. Firstly, the acoustical energy of the shot is estimated. Secondly, directionality of the source is applied and the spectrum is calculated on the basis of an acoustical blast model of explosions in air. As an engineering requirement, the procedure should always yield a 'reasonable' guess. In addition, the procedure should accept more specific input data if available to improve the result. Therefore, in most steps the procedure here allows alternatives, a default value or a better known specific number.

In Fig. 1 the left part of the flow chart shows the way to estimate the total acoustic energy that is used in the right part of the flow chart to determine the acoustical source data. Branches in the flow chart that are alternatives are always joined by \oplus . The symbol \otimes means that both sets of information are needed to continue. The symbols \hat{x} denotes an input number for the parameter x . Numbers at the top of some forms indicate the formulas or tables.

The key quantity to estimate the acoustical energy is the total chemical energy involved, E_c . There are two alternatives to determine E_c if it is not known directly. The left hand branch uses the kinetic energy of the projectile E_b , either known directly or alternatively calculated from the mass and launch speed of the projectile (formula 1). The bullet energy is a fraction f_{cb} of the total energy depending on the shot. If the fraction f_{cb} is not known, 35% should be used as default. Formula 2 then determines E_c . The right hand branch uses the mass of propellant or explosives. The conversion factor f_{cm} depends on the type of propellant (for example 4,310 J/g for TNT, or 5,860 J/g for PETN). If the specific f_{cm} is not known $f_{cm} = 4,500$ J/g should be used.

The energy E_c is partially converted into heat and kinetic energy of the remaining gas E_g , heat and friction of barrel and projectile, and the kinetic energy of the bullet E_b or accelerated material, respectively. The inner ballistics, in case of guns, will determine this balance, /1/. A fraction of 45% in E_c should be used as default of E_g . E_g is the only source for the muzzle blast. Formula 4 accounts for the efficiency of the conversion of gas energy E_g into acoustic energy E_a .

The part on the right of Fig. 1 shows the flow chart to determine the acoustical energy flow density E_{density} generated by the shot in a certain direction on the basis of the acoustical energy. E_{density} measures the total energy of the shot flowing through a unit area in the direction under consideration and therefore indicates free field sound exposure in acoustical terms.

For symmetric radiation around the line of fire, the directionality of the source is described by a Fourier-series with respect to the aspect angle φ relative to the line of fire. Therefore, the angle φ denotes a slice of a sphere. Hence the areas of these slices depend on φ , Formula 8 corrects this influence of geometry with respect to the directivity pattern and calculates the effective part E_e of the acoustical energy. If the directivity pattern c_n is not known, formula 6 gives a list of default values for some devices. Applying the directivity D to E_e in formula 10 yields the energy that flows through the slice including the directionality of the source.

The next two steps in formulae 11 and 12 use a simple acoustical model of explosions in air to estimate the desired Fourier-spectrum of the blast in the direction φ . This model is described in more detail elsewhere /2/. Though the parameters E_w and P_w are given as alternatives, both parameters do not depend on a specific shot. The default values are validated model parameters and should not be changed without important reasons. Formula 12 can be written in many different ways but there is no analytical way to integrate for an one-third octave spectrum for example. In general, the acoustical blast model provides a complex spectrum including information about the phase. However, due to non-linear sound propagation effects close to the source, deduced time signals are not reliable though they are looking quite reasonable. Therefore, this estimation method should not be used for the prediction of pressure peak values or similar measures.

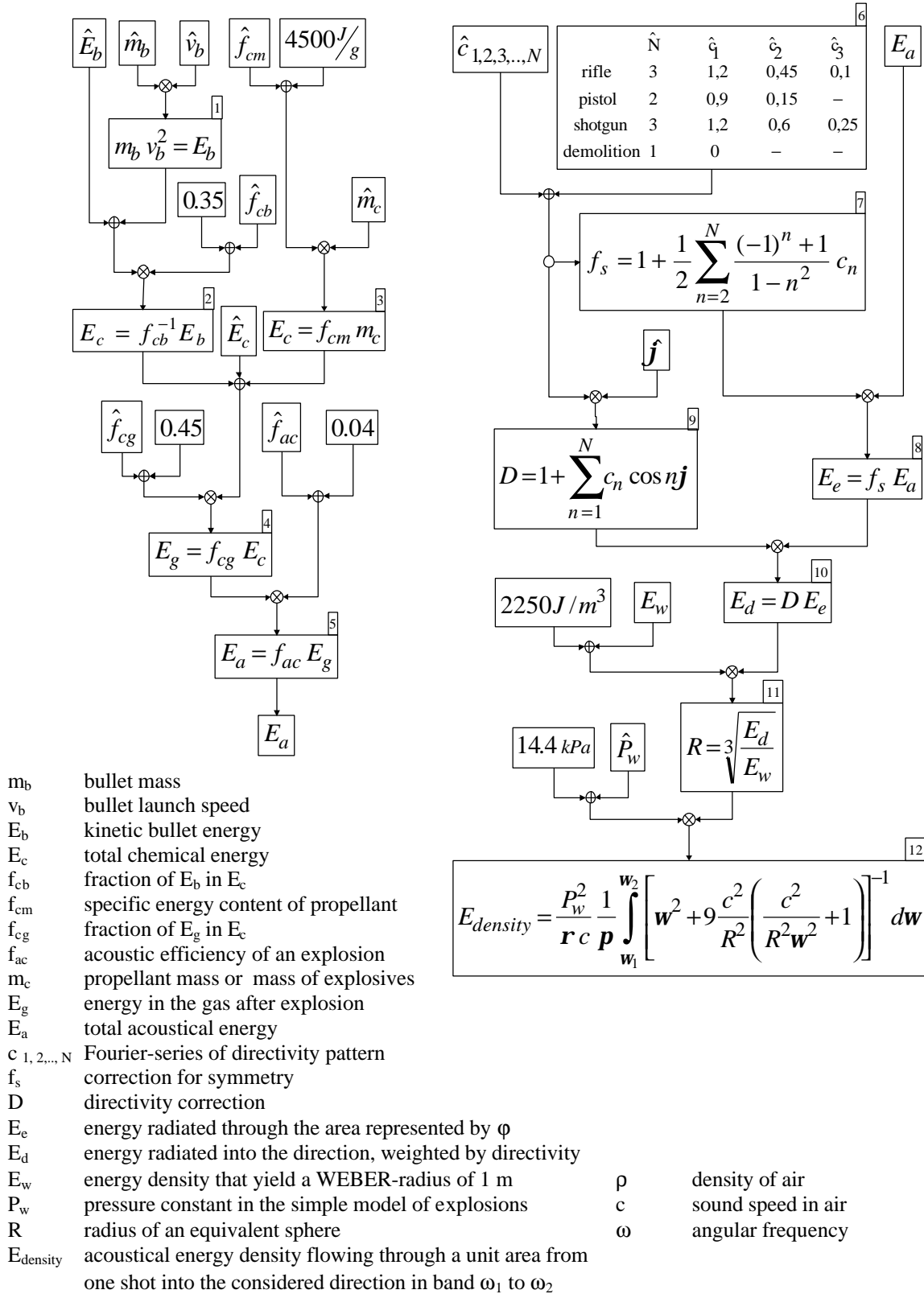


Fig. 1 Flow chart for the estimation procedure to determine spectral acoustical source data for muzzle blasts from gun firing and for explosions on the basis of poor input data

DISCUSSION

At first sight, the estimation method looks rather complicated due to the alternatives given in the flow chart. However, always choosing the default values reduces the effort a lot and yields a rather comprehensive way to make a first guess of blast source data. The given general default values are not yet sufficiently validated, though they result from test data including very different weapons like pistols, rifles, explosions and even large military guns. It is a further step to deduce improved values and adopt the approach for the different types of blasts.

Note: It is typical for shooting noise that the exchange or comparison of available measured data is not very helpful because the data are not acquired in the same way. Published data sets often focus directly on weighted acoustical levels according to national standards and do not provide enough information about the source with respect to ammunition and/or measuring technique. The test plan prepared by the WG 51 will give guidance on how to find the physical target measures and an appropriate measuring technique.

This method should not replace measurements. It is an engineering method that yields results even for poor input data. There are some important advantages. This approach

- really yields a spectrum.
- naturally considers the spectral shift to lower frequencies if acoustical energy is increased.
- takes care about spectral directionality using only the directivity pattern of the energy flow.
- is not restricted to small arms; it should cover the whole range of civil and military weapons.
- is neutral with respect to acoustical weightings as long as energy measures are concerned.
- relies on the energy concept in each step and therefore supports the estimation of errors.
- traces the various influences on the acoustical output to physical phenomena.
- avoids artificial corrections based on relationships between basically unrelated parameters.

The conclusions in /2/ state that there is a sufficient high correlation between propellant mass and the true acoustical source energy within an uncertainty of ± 3 dB. The paper also discusses how the directional spectrum depends on this energy. If ± 3 dB is an acceptable range of prediction error this approach can come close to such a range. However, the directionality of the blast is the most uncertain factor.

CONCLUSION

The proposed estimation method is at this stage, a draft approach that needs discussion, improvement and validation. Considering the method as, at least, a guided tour from weapon input data to an acoustical source spectrum, the flow chart highlights the complex influences of the important phenomena on the result. The major advantage of this approach is that more sophisticated methods or models can replace each step. The purpose of this paper is primarily to start the discussion and invite experts to check their data against it.

ACKNOWLEDGEMENTS

The German Ministry of Defense supports these investigations.

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