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Attenuation of Acoustic Waves from Targets by Atmosphere

P. Melša*

Department of Weapons and Ammunition, University of Defence, Brno, Czech Republic

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Abstract:

Acoustic detection of adversary land targets is interlinked with transmission of environment acoustic waves – atmosphere. The solution of this problem of acoustic exposure of target and acoustic transmission of information in atmosphere makes it possible to specify important dates about target of interest.

Keywords:

Acoustic wave, wave attenuation, atmosphere, humidity, detection, target.

1. Introduction

The enemy target detection via the acoustic way is closely connected with the problems of the transmission channel – the atmosphere in this case. The information about the target can be widely improved by solution of the problems connected with transmission channel behaviour and target acoustic characteristic. The description of the acoustic wave propagation is usually linked to neglecting of the atmosphere (transmission channel) characteristics. Alternatively the result data are partially corrected only.

2. The atmospheric spatial influence on the acoustic wave propagation

The attenuation of the acoustic wave in the atmosphere depends on air composition with significant influence of water vapour concentration. According to ISO 2533 the standard atmosphere [1], defined as a clean and dry air at the sea level, consists of 78.084 % of nitrogen, 20.9476 % of oxygen and 0.0314 % of carbon dioxide. The rest percentage, i.e. 0.937 % of the dry air pertains to trace elements that have no effect on acoustic wave attenuation. It is valid for dry atmosphere only. The water vapour

* *Corresponding author: Department of Weapons and Ammunition, University of Defence, Kounicova 65, CZ-662 10 Brno, Czech Republic, phone: +420 973 445 176, E-mail: pavel.melsa@unob.cz*

concentration broadly varies. The atmospheric humidity has influence on atmospheric attenuation.

The increase of the acoustic pressure amplitude of the harmonic tone propagating through the atmosphere is described as an exponential increase characteristic. Thus for current acoustic pressure amplitude p_t at the distance s it is valid [2]:

$$p_t = p_i \exp(-0.1151 \alpha s) \tag{1}$$

where p_i is the initial acoustic pressure amplitude, α is the attenuation coefficient, s is *the* distance of acoustic source, and constant 0.1151 means $1/[10 \log(e^2)]$.

The attenuation of the atmosphere $\delta L_t(f)$ [dB] for harmonic tone with frequency f is then defined [2]:

$$\delta L_t(f) = 10 \log(p_i^2 / p_t^2) = \alpha s \tag{2}$$

In agreement with Avogadro's Law, the molar concentration of water vapour is equal to the ratio of partial water vapour pressure to atmospheric pressure. The water vapour molar concentration ranges from 0.2 % up to 2 % for normal conditions at the sea level. However, it increases under the 0.01 % for the high over 10 km above the sea level.

The atmospheric attenuation, according to [2], is a function of two frequencies of relaxation: the oxygen frequency of relaxation f_{rO} and nitrogen frequency of relaxation f_{rN}. The values of these frequencies are determined by the following equations:

$$f_{rO} = \frac{p_a}{p_r}\left(24 + 4.04 \times 10^4 h \, \frac{0.020 + h}{0.391 + h}\right) \tag{3}$$

$$f_{rN} = \frac{p_a}{p_r}\left(\frac{T}{T_0}\right)^{-1/2}\left\{9 + 280 h \exp\left[-4.170\left(\left(\frac{T}{T_0}\right)^{-1/3} - 1\right)\right]\right\} \tag{4}$$

where p_a is atmospheric pressure in kPa, p_r is reference atmospheric pressure (101.325 kPa), T is atmospheric temperature in K, T_0 is reference temperature (293.15 K) and h is molar concentration of water vapour in %.

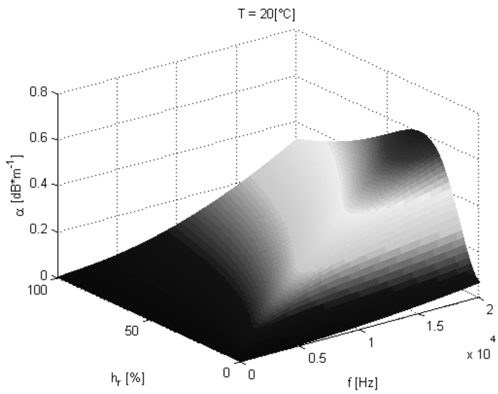
Coefficient of attenuation caused by atmosphere α [dB/m] is expressed:

$$\alpha = 8.686 f^2 \left\{1.84 \times 10^{-11}\left(\frac{p_a}{p_r}\right)^{-1}\left(\frac{T}{T_0}\right)^{1/2} + \left(\frac{T}{T_0}\right)^{-5/2} \times \right.$$
$$\left. \times \left[0.01275\left(f_{rO} + \frac{f^2}{f_{rO}}\right)^{-1} \exp\left(\frac{-2239.1}{T}\right) + 0.1068\left(f_{rN} + \frac{f^2}{f_{rN}}\right)^{-1} \exp\left(\frac{-3352.0}{T}\right)\right]\right\} \tag{5}$$

Equations (3) to (5) are sufficient for the determination of the coefficient of attenuation of harmonic tones propagating through the atmosphere the temperature of which is T.

The examples of calculations of frequency attenuation of acoustic waves during passage through atmosphere for different atmospheric humidity and atmospheric pressure are in Figs 1 and 2.

a)



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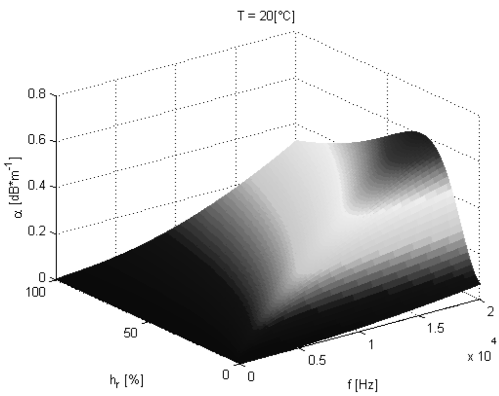

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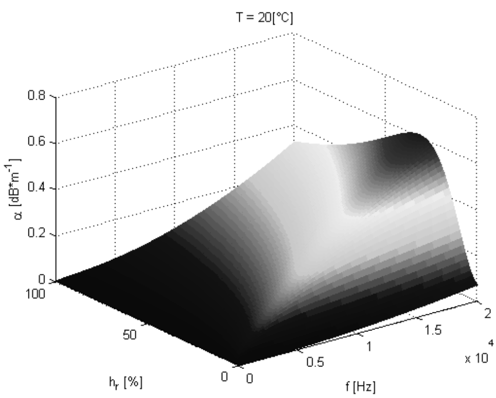
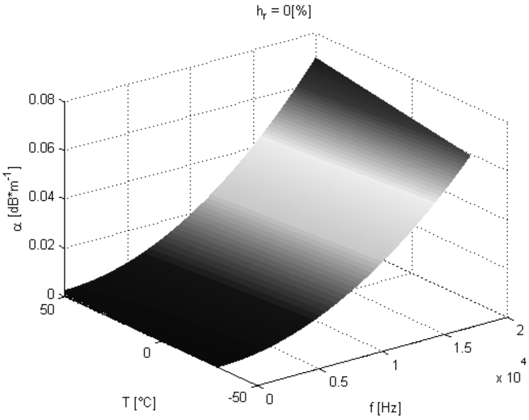


Fig. 1 Frequency attenuation of acoustic waves in atmosphere for one atmospheric temperature, different atmospheric humidity and atmospheric pressure: a) atmospheric pressure p_a = 95 kPa, b) atmospheric pressure p_a = 101.325 kPa, c) atmospheric pressure p_a = 105 kPa.

a)



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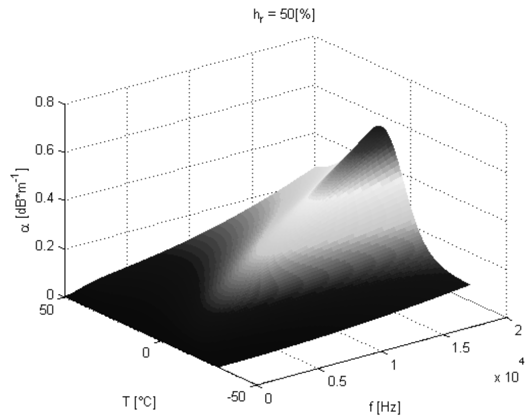

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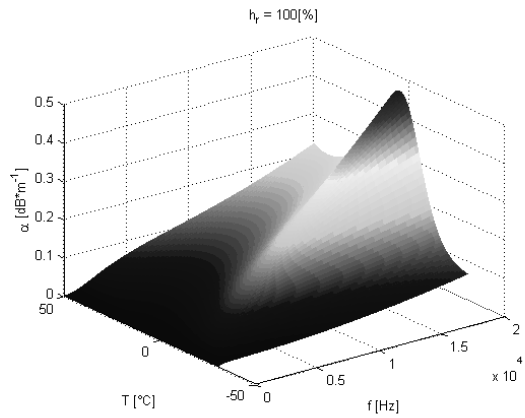

Fig. 2 Frequency attenuation of acoustic waves in the atmosphere for one atmospheric pressure (atmospheric pressure p_a = 101.325 kPa), different atmospheric humidity and atmospheric temperature: a) atmospheric humidity h_t = 0 %, b) atmospheric humidity h_t = 50 %, c) atmospheric humidity h_t = 100 %.

Fig. 1 shows diagrams for one atmospheric temperature (+20 °C) and for three atmospheric pressures: p_a = 95 kPa, p_a = 101.325 kPa and p_a = 105 kPa. The diagrams are equivalent. It can be observed that the atmospheric pressure has no influence on frequency attenuation of acoustic waves. Maximum frequency attenuation of acoustic waves is for atmospheric humidity about 35 %.

Fig. 2 shows the diagrams for one atmospheric pressure p_a = 101.325 kPa and for three different values of atmospheric humidity: h_t = 0 %, h_t = 50 %, h_t = 100 % and different atmospheric temperatures. The diagrams are different here. it is apparent that atmospheric frequency attenuation has different values. When atmospheric humidity is 0%, the atmospheric attenuation is small. For atmospheric humidity higher then 0 % the atmospheric attenuation is increased and simultaneously more selective. The maximum value of atmospheric frequency attenuation is about temperature of 0 °C.

This information is important for the detection, recognition and identification of the lands targets.

We know, how atmosphere have of influence of distortion and attenuation acoustic signals. For example, we detected gun shot signal by 152mm self-propelled gun-howitzer M77 Dana (see Fig. 3) and we want to detect, recognize and identify this target [3].

Acoustic frequency spectra of signals – original and after passing through the atmosphere from the distance of 6 km – are in Figs 4 and 5. The acoustic frequency spectra of this signals are similar (see Fig. 6) with correlation ratio R = 0.7439. When the correlation ratio R of acoustic signals is bigger than 0, the acoustic target is detected; when the correlation ratio R of acoustic signals is from 0.5 to 0.8, acoustic target is recognized and when the correlation ratio R of acoustic signals from is 0.8 to 1, acoustic target is identified.

The atmosphere more attenuates higher frequency. We can see that we can recognize some acoustic signal by some gun only, but we do not know the type of gun.

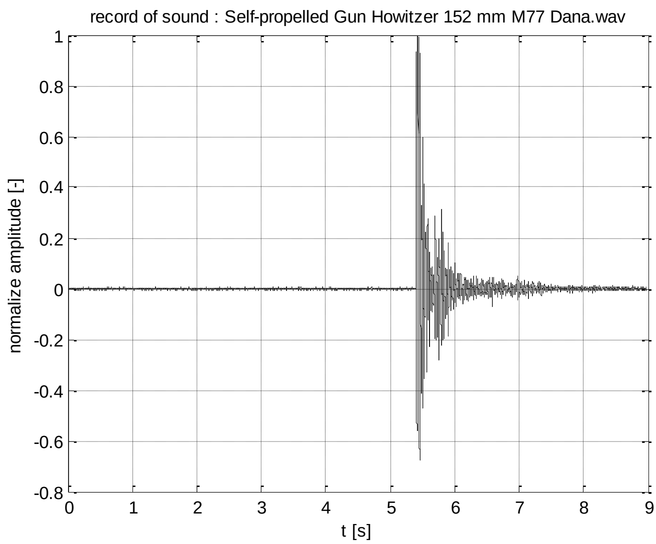

Fig. 3 Acoustic signal of gun shot – original (distance from acoustic source – target – to acoustic sensor d = 20 m)

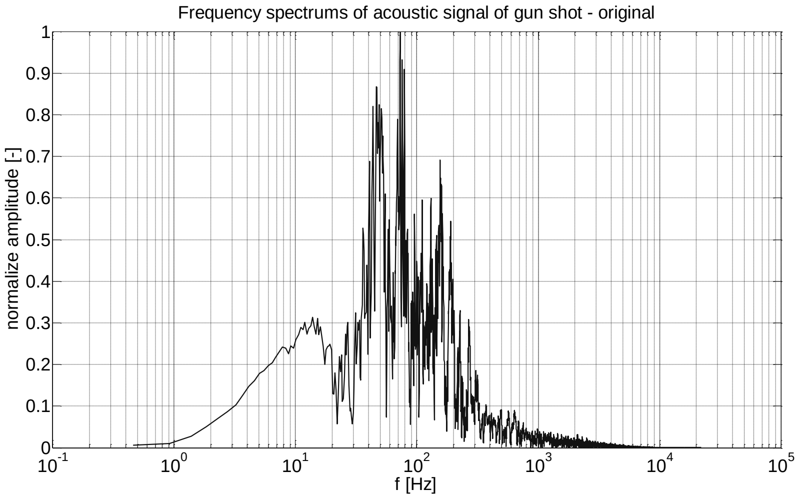

Fig. 4 Frequency spectrum of acoustic signals of gun-shot – original (p_a = 101.325 kPa, atmospheric humidity h_t = 60 %, atmospheric temperature t = 25 °C, distance from target to acoustic sensor d = 20 m)

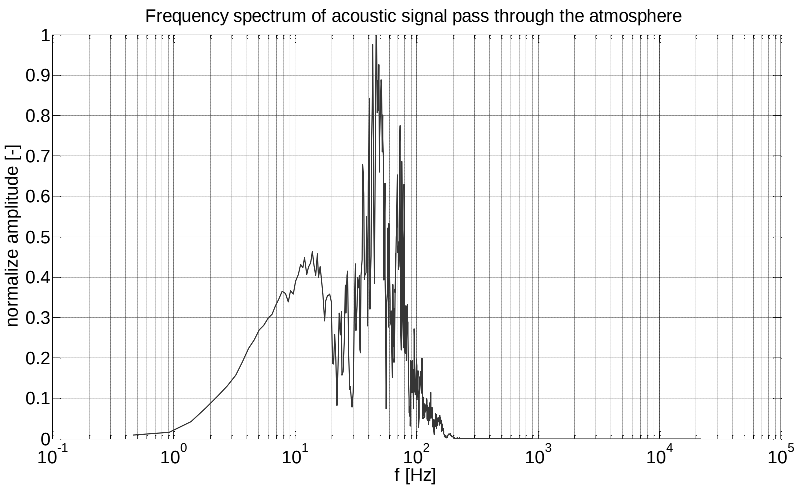

Fig. 5 Frequency spectrum of acoustic signals passing through the atmosphere (p_a = 101.325 kPa, atmospheric humidity h_t = 60 %, atmospheric temperature t = 25 °C, distance from target to acoustic sensor d = 6 km)

3. Conclusion

The atmosphere is for acoustical signal as low pass filter. The atmosphere is like pass filter not only for frequencies of acoustical waves. Its attenuation for this wave strongly depends on atmospheric conditions of record of acoustical waves from special-interest source. The atmosphere temperature and atmosphere humidity have great impact on acoustical attenuation from the point of view of distortion this acoustic signals. The knowledge of acoustical attenuation of atmosphere is important for passive military detection, recognition and identification of land targets on base their acoustical exhibitions.

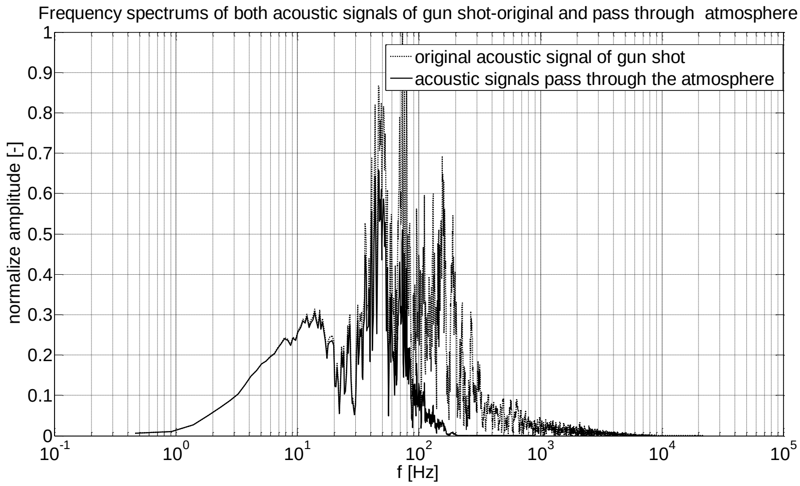

Fig. 6 Frequency spectrum of acoustic signals of gun shot – original and the frequency spectrums of acoustic signals passing through the atmosphere

References:

[1] ISO 2533:1975. *Standard Atmosphere.*

[2] ISO 9613-1:1993 *Acoustics – Attenuation of sound during propagation outdoors – Part 1: Calculation of the absorption of sound by the atmosphere*.

[3] MELSA P. *The Detection of Acoustic Waves of Land Targets* (in Czech) [PhD Thesis]. Brno: University of Defence, 2011. 136 p.

[4] Institutional research plan MO0FVT0000402 *Research into passive optic-electronic systems of automatic target tracking for fire-control systems*. The Research and Development Innovation Information System of the Czech Republic. [cited 2012-05-16]. Available from: <http://www.isvav.cz/researchPlanDetail.do?rowId=MO0FVT0000402>.

Acknowledgement

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