INFLUENCE OF METEOROLOGICAL CONDITIONS ON PROPAGATION OF SOUND

Milan DRAHOŠ[1], Richard Drahoš[1,2]

[1] D2R engineering, s.r.o., Na letisko 42, 058 01 Poprad, Slovakia, d2r@d2r.sk
[2] Technical university of Košice, Faculty of Mechanical Engineering, Department of environmentalistics, Park Komenského 5, 042 00 Košice, Slovakia, richard.drahos@d2r.sk

Abstract: *Effect of meteorological conditions to change sound pressure A levels measured in the outer space is characterized by a radius R sound beam curve. To ensure favorable meteorological conditions for sound propagation above ground are for the corresponding period of the day specified the requirements related to the cloud amount, location of source / microphone, their apart distance and wind speed in the direction of sound*

1. INTRODUCTION

Meteorological elements and phenomena's in ground layer of atmosphere significantly influence propagation of sound waves at longer distances. This influence is caused mainly due to acoustics refraction, i.e influence of vertical temperature and wind gradient and atmospheric absorption.

There are always present significant temperature and wind gradients in open space in vertical direction. Temperature gradients are created due to heat transmission between earth ground and atmosphere. Wind gradients are created due to friction between moving wind mass and earth ground. In specificall meteorological situation areas of acoustical shadow can be created. These areas are not sharply bordered because acoustics energy is refracted into shadow area by atmospheric turbulency.

2. SOUND PROPAGATION OVER EARTH GROUND

Sound velocity is rising with temperature that's why when the positive temperature gradient is present (usually during the night, when temperature in higher layers of atmosphere is higher than on earth ground) sound waves are bending towards earth ground and the phenomena of sound propagation amplification can occur. Vice-versa when the negative gradient is present (during the day) are warmer layers of air usually near to heated earth ground and sound waves are bending towards terrain causing acoustics (sound) shadow. On figure 1 is shown influence of temperature gradient on sound propagation during windlessness.

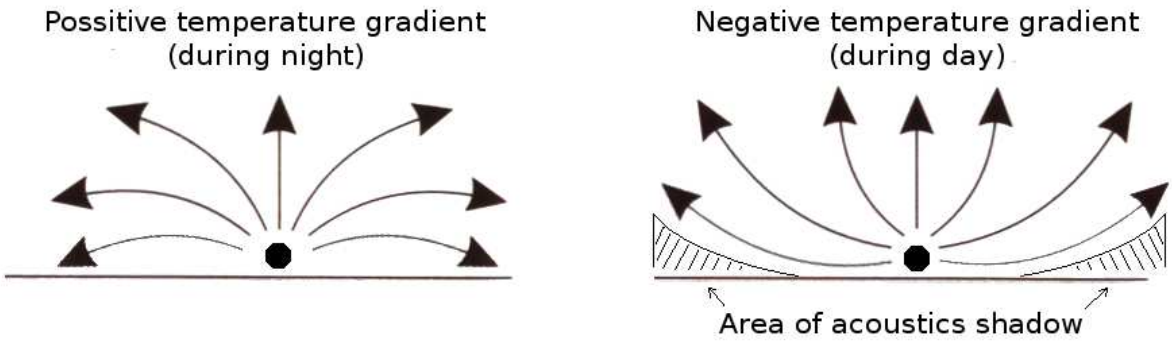
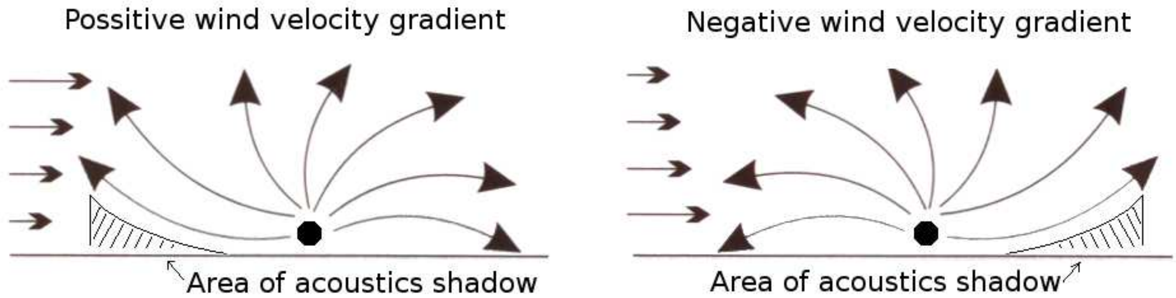


Fig. 1: Influence of temperature gradient on sound propagation during windlessness

In case of positive wind gradient, i.e if velocity in higher layers of atmosphere is higher, then in opposite wind direction are sound waves bending from earth ground causing acoustics shadow near to ground. In wind direction are sound waves bending towards earth ground causing sound propagation amplification. On figure 2 is shown influence of wind gradient on sound propagation.



Obr. 2: Influence of wind gradient on sound propagation

It is obvious from model figures that imaginary radius of sound curve beam over terrain surface (up to 30 m altitude) can express influence of meteorological conditions on sound propagation in open space without obstacles.

Sound attenuation in atmosphere depends also on atmospheric absorption, i.e on ambient temperature, relative humidity and sound frequency. Calculation of sound absorption in atmosphere is described in ISO 9613-1:1993 Acoustics. Attenuation of sound during propagation outdoors. Part 1: Calculation of the absorption of sound by the atmosphere.

Atmospheric refraction and atmospheric absorption are dependent on changing state of atmosphere over earth ground. Sound attenuation is influenced also by earth ground absorbtion changing according to season.

3. INFLUENCE OF ATMOSPHERIC REFRACTION ON SOUND PROPAGATION

The influence of atmospheric refraction on acoustic pressure A level change (fluctuation) in specific point is described in appendix A in standard ISO 1996-2:2007 Acoustics. Description, measurement and assessment of environmental noise. Part 2: Determination of environmental noise levels. This influence id describes as radius *R* of sound beam curve.

During horizontal sound propagation near to earth ground is diameter R (which approximate sound beam curve caused by atmospheric refraction) determined by formula:

$$R = \frac{c(\tau)}{\frac{k}{\sqrt{\tau}} \frac{\partial \tau}{\partial z} \frac{\partial u}{\partial z}}$$

where $c(\tau) = c_o \sqrt{\tau}$ - phase sound velocity in m.s^{-1}, where $c_o = 20{,}05 \frac{m}{s\sqrt{K}}$,

u – sound velocity component in direction of sound propagation in m.s^{-1},

k - constant $k = 10 \frac{m}{s\sqrt{K}}$,

τ - absolute ambient temperature in ^{o}K,

z - height above earth surface in m.

If the temperature and wind velocity difference in height 10 m and 0,5 m above earth ground is known, than the value of radius R can be approximately calculated from formula:

$$R = \frac{3{,}2}{0{,}6\Delta\tau + \Delta u \cos\theta}$$

where $\Delta\tau$ – difference value between ambient temperature in ^{o}K in height 10 m and 0,5 m above earth surface,

Δu - difference value between wind velocity in m.s^{-1} in height 10 m and 0,5 m above earth surface,

θ – angle between wind direction and direction from sound source to receiver (microphone).

Sound beam curve radius R depends on average temperature gradient and wind speed and is the most important factor that determines sound propagation conditions. If the R is positive, sound beam curve direction is downward (in case of sound propagation from source in wind direction or during temperature inversion during night. If the R is negative, sound beam curve direction is upward (in case of sound propagation from source against wind direction or during windless day in summer. In case of homogenous atmosphere and windless conditions sound propagation path is straight and curve radius $R = \infty$.

The influence of atmospheric refraction during measurement of sound pressure A level in case of absorptive terrain surface don't need to be take into account if this condition is fulfilled:

$$\frac{h_z + h_m}{d} \geq 0{,}1$$

where h_z - source height above terrain,

h_m – microphone height above terrain,

d – distance between source and microphone.

If this condition is not fulfilled, atmospheric refraction can influence the measurement results. In common situations during measurement are in subparagraph A.1 in appendix A of standard described two positions:

a) high position: $h_z \geq 1,5$ m and $h_m \geq 1,5$ m or $h_z < 1,5$ m and $h_m \geq 4$ m,
b) low position: $h_z < 1,5$ m and $h_m \leq 1,5$ m.

Favorable meteorological conditions for sound propagation occur, if the sound beam curve radius *R* is positive (for instance wind direction from source to microphone and beam bending downward), than sound pressure A level up to 400 m distance is higher and fluctuation is lower. Favorable meteorological conditions for sound propagation are accepted also for negative sound beam curve radius *R*, but only in case of high position up to 200 m distance.

4. CONDITIONS INFLUENCING SOUND BEAM CURVE RADIUS

In regard of fact, that temperature gradient is close related with sun position (height) over horizont, in figure 3 are shown areas A, B, C, D for time periods of the day, months in year and 56° north latitude, where temperature gradient is in definite boundaries.

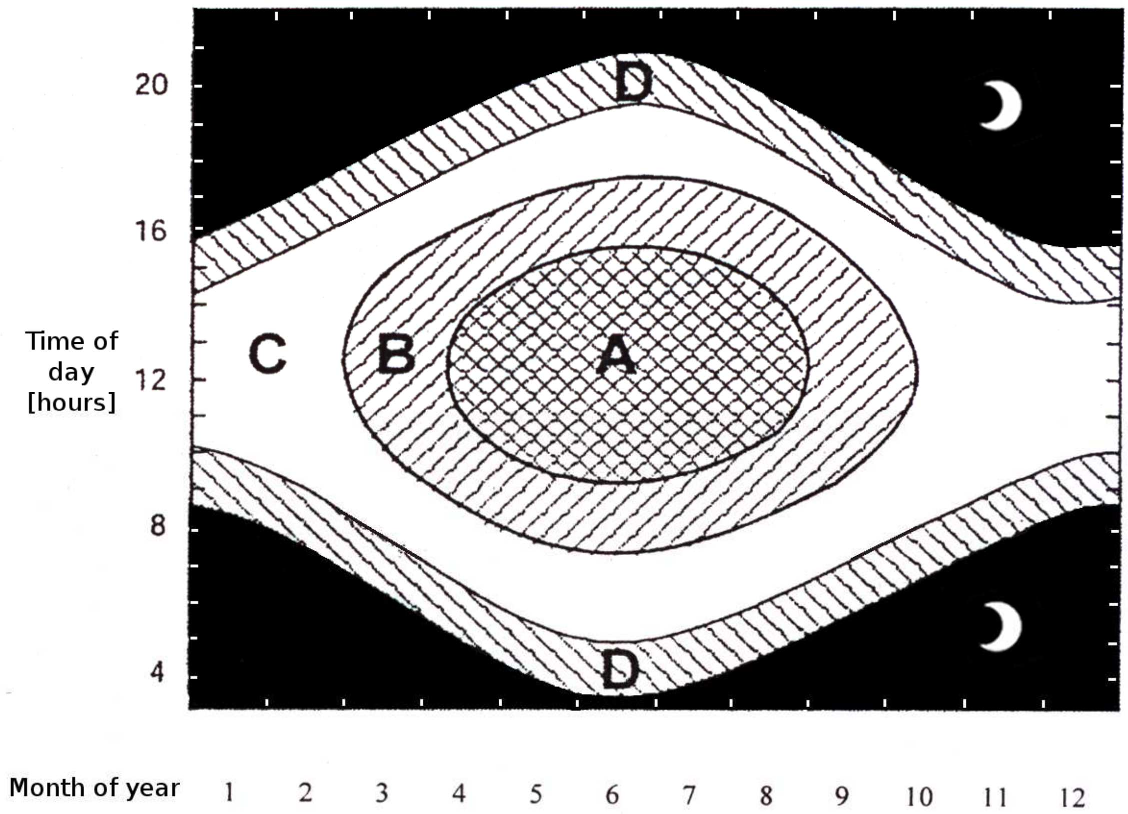


Fig. 3: Time periods of the day for sun over horizont, 56° north latitude

Area A represents time interval, when sun is from 40° to 60° over horizont, i.e this area represents midday. Area B represents time interval, when sun is 25° to 40° over horizont, i.e this area represents morning and evening during summer and midday during spring and autumn. Area C represent time interval, that is not included in areas A, B and D. Area D represents time interval between from sunrise till 1,5 hour after sunrise and from 1,5 hour before sunset and sunset.

5. REQUIREMENTS FOR FAVORABLE CONDITIONS FOR SOUND PROPAGATION

To fulfill favorable conditions for sound propagation in corresponding time period of day, i.e. in areas A, B, C, D, the lowest values of wind velocity in height of 10 m above ground are required. Because wind speed depends on cloud amount, in table 1 is shown values of cloud amount which ensures required radius *R* sound beam curve.

Time period of day	**Claud amount** (in eight of covering sky with clouds)	**The lowest value of wind speed in height of 10 m in m.s^{-1}**	
		***R* < - 10 km high position *d* >50 m**	***R* < 10 km low position *d* >25 m**
A	(8/8) overcast – low clouds	0,4	1,3
	(6/8 až 8/8) overcast	1,2	2,0
	(< 6/8) partly cloud	2,0	2,7
B	(8/8) overcast – low clouds	0,2	1,2
	(6/8 až 8/8) overcast	0,9	1,7
	(< 6/8) partly cloud	1,6	2,3
C	(8/8) overcast – low clouds	0	0,9
	(6/8 až 8/8) overcast	0,3	1,3
	(< 4/8) partly cloud	0,8	1,7
Night	(6/8 až 8/8) overcast	0,1	> 0,5
	(< 6/8) partly cloud	Wind speed ≥ 2 m.s^{-1}	
D	Measurement only near source		

Table 1: Values of cloud amount which ensures required radius *R* sound beam curve

For instance to fulfill requirement for *R* < 10 km at low position of source/microphone and distance d > 25 m in time period of the day identified in:

a) area A, during overcast with thick clouds, wind speed in direction of sound beam has to be *1,3 m.s^{-1}* or more. During partly cloudy or clear sky conditions wind speed in direction of sound beam has to be 2,7 *m.s^{-1}* or more,

b) area B, during cloud amount less than 6/8 (partly cloudy) wind speed in direction of sound beam has to be 2*,3 m.s^{-1}* or more,

c) area C, during cloud amount less than 4/8, wind speed in direction of sound beam has to be 1,7 *m.s^{-1}* or more.

During time period specified in area D huge local temperature differences can occur, that’s why it is not recommended to perform measurements on longer distances from source of sound.

During night, when cloud amount is more than 6/8 it is only small component of wind speed required downwind in direction of sound beam. If the cloud amount during night is less than 6/8, huge local temperature gradients can occur, that’s why component of wind downwind in direction o sound beam has to be 2 m.s^{-1} or more in order to exclude special influences on sound propagation, i.e. inversion condition.

In case of one dominant sound source the requirement *R* < 10 km is fullfiled if:

a) wind direction is in range ± 60° from direction source/microphone and sound is propagating downwind,
b) wind velocity measured in height form 3 m to 11 m above terrain is from 2 to 5 $m.s^{-1}$ during day and or more than 0,5 $m.s^{-1}$ during night,
c) there is no major negative temperature gradient (local temperature inversion) near to the sound source.

6. UNCERTAINTY CAUSED BY ATMOSPHERIC REFRACTION

Contribution to the uncertainty of sound pressure A levels measurement results due to atmospheric refraction is in standard expressed by standard uncertainty - standard deviation σ_m. Value of σ_m varies depending on the position source / microphone, and their distance and from the existing meteorological situation in the time interval of measurement.

In favorable conditions for sound propagation over unshielded, flat and porous surface in ISO standard is estimated value of standard deviation, depending on the location of source / microphone up to distance of 400 m. (Figure 4).

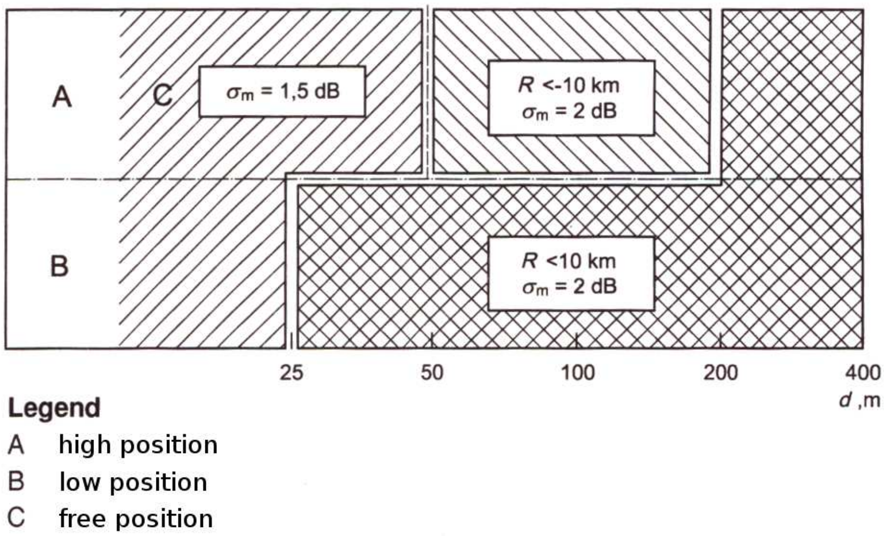


Fig. 4: Estimated standard deviation σ_m influenced by favorable condition over porous terrain

In distances longer than 400 m, in the radius of sound beam curve *R* <10 km standard deviation is σ_m= 1 + *d*/400.

In case that the terrain between the source and the microphone is acoustically hard, the standard deviation can be neglected up to a distance unless an acoustic shadow occur.

7. CONCLUSION

It is appropriate to make measurements under favorable meteorological conditions for sound propagation in order to comparable results of outdoor measurements of sound pressure A levels.

To ensure favorable conditions for sound propagation over ground without obstacles in day time period and the corresponding month of the year are set out requirements relating to the location of the source and the microphone, their distance apart, clouds (clouds of the sky level) and the minimum value of the components of the wind speed in the direction of the sound beam.

The question that remains is application of uncertainty components by atmospheric refraction σ_m in overall balance of sources of uncertainty during measurements in outer space. Reason for that question is that this component of uncertainty changes with height of source and microphone and depends also from existing meteorological elements (weather) particularly during long-term measurements.

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