Sound control in windy weather

Master Thesis

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Preface

This report is composed by Jonas Buchholdt during the 10th semester of Electronic Engineering and IT at Aalborg University. The general purpose of the report is *Signal Processing and Acoustics* .

For citations, the report employs the Harvard method. If citations are not present by figures or tables, these have been made by the authors of the report. Units are indicated according to the SI standard.

Aalborg University, February 19, 2019

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ACE Air Conduction Earphones. 27

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SPL Sound Pressure Level. 7, 8, 10

Chapter 1

Introduction

Comes later

Part I

Problem Analysis and Requirements

Chapter 2

Analysis of sound propogation in outdoor venue

2.1 Live venue sound challenges

This section explore the challenges of producing sound in an outdoor environmental. The challenge of producing a good sound experience for the audience highly depend on the calibration method and the atmosphere condition. It is well known that acoustically wave propagation is strongly affected by the inhomogeneous atmosphere doing the outdoor sound propagation. This inhomogeneous atmosphere shifts the calibration of the sound system which affect the intelligibility. The following section address the impact of the homogeneous effect and the inhomogeneous effect on wave propagation.

2.2 Homogeneous atmospheric conditions

The aim of this section is to analyses the sound wave propagation in a homogeneous atmospheric conditions. It is well known that the propagation is highly depending on the atmospheric conditions, and the effect is not linear in frequency for some type of atmospheric condition. The wave propagation is depending on atmospheric pressure, wind, temperature and humanity, where the two latter also is frequency dependent. The attenuation difference in frequency can be above 80 dB Sound Pressure Level (SPL) [Corteel et al., 2017]. The resulting attenuation is expressed as an frequency depending absorption coefficient in dB pre meter. The following sections will make a short introduction to the homogeneous atmospheric conditions effect on sound propagation. All section will be based on far field condition, which indicate that the spreading loss is 6 dB SPL per doubling of distance and a plan wave, while the atmospheric conditions is excluded [Bauman et al., 2001],

2.2.1 Geometric spreading loss

When a line source generate a sound wave, the wave field exhibits two difference spatially directive regions, near field and far field. In near field the wave propagate as an cylindrical wave where in the far field the wave propagate as a spherical wave. When the wave propagate as a cylindrical wave, the wave propagate only horizontally and therefore the attenuation is 3 dB SPL per doubling of distance. For a spherical wave propagation, the wave propagate in all direction and therefore the attenuation is 6 dB SPL per doubling of distance. The near field and far field attenuation is based on non absorption homogeneous atmospheric conditions. The border between the near field and far field is dependent on the hight of the array and the frequency. The distance can bi calculated with Fresnel Equation 2.1 where where the wavelength λ is approximated to $\frac{1}{3f}$ [Bauman et al., 2001]

$$d_B = \frac{3}{2} f \cdot H^2 \sqrt{1 - \frac{1}{(3f \cdot H)}} \tag{2.1}$$

Where:

d_B	is is the distance from the array to the end of near field	[m]
f	is the frequency	[kHz]
H	is the hight of the array	[m]

In equation Equation 2.1 it can be seen that the less than 80 Hz radiate directly intro spherical wave on the exit of the speaker. The following Figure 2.1 shows an 2D description of the near field, far field.

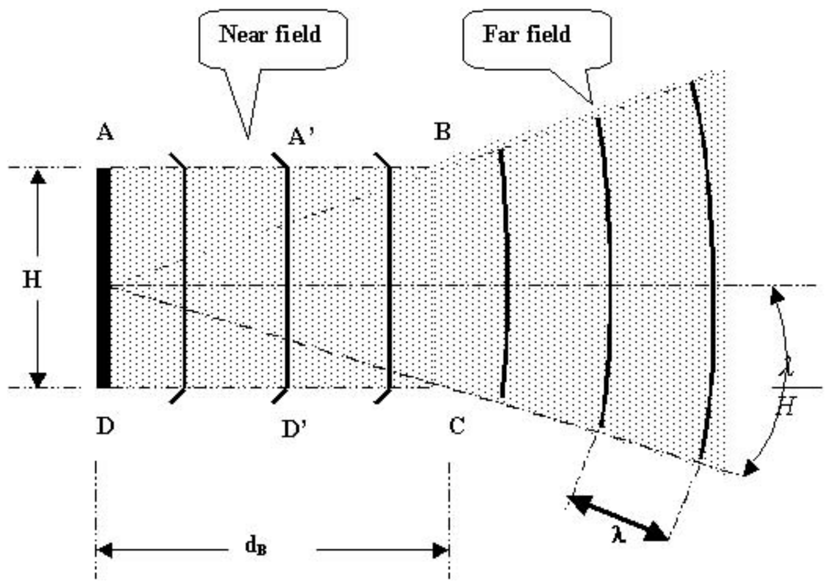

Figure 2.1: The figure shows horizontal cut of a SPL radiation pattern of a line source array [Bauman et al., 2001].

2.2.2 Humanity and temperature impact

The temperature and humanity has two impact on wave propagation, speed of sound and a lowpass effect. The following description starts with the latter.

Lowpass effect The effect of humanity and temperature is a lowpass filter, where it mostly not affect the low frequency. In other words, attenuation in the high frequency range per doubling of distance in far field will depends not only on the spreading loss, but also on temperature and humanity. Therefore, for long distance, the atmospheric conditions has a high effect on the frequency spectrum delivered to the audience. The humanity and temperature attenuation is already well studied and standard [ISO 9613-1:1993] gives an overview of calculating the frequency attenuation with respect to the distance, temperature and humanity. The article [Corteel et al., 2017] gives some examples of attenuation at a distance of 100 m. The article [Corteel et al., 2017] shows, if the humanity increases proportional to the temperature, the lowpass effect is small. If the change in temperature and humanity is opposite of each other, for example the high temperature but dry, the attenuation in the high frequency is significant. The following Figure 2.2 shows the worst case senaio from [Corteel et al., 2017].

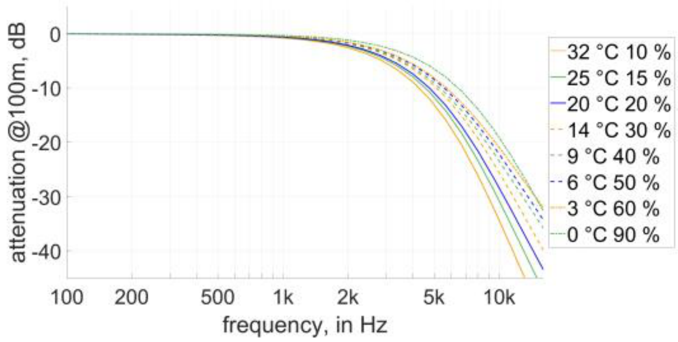

Figure 2.2: The graph shows the attenuation in dB with respect to frequency, humanity and temperature [Corteel et al., 2017].

Speed of sound The second impact is the speed of sound. At temperature range from 0 °C to 40 °C the speed of sound with respect to humanity change is spars and mostly only depend on temperature change. The speed of sound is raises approximate by 0.6 m/s for every degree Celsius. The speed start at 331 m/s at 0 °C and 0 % humanity. The following TABEL show the speed of sound with respect to humanity and temperature.

2.2.3 Wind impact

The wind impact is complex and is not homogeneous with respect to sound source. The impact is depending on the angle of the wind direction with respect to the direction of sound propagation.

Parallel to sound propagation When the wind gradient is going the same or opposite direction as the sound propagation, the relation between the speed of sound and the speed of wind is a linear system. Therefore the speed of wind shall just be added to the speed of sound. In all other cases the impact is complex since the wind deflect the sound waves.

oblique- and crosswind The effect of oblique- and crosswind on acoustical wave propagation is rare studied and the effect seems to be unclear. Few author have addressed the problem in a simulation of traffic noise and by practical experience [de Oliveira, 2012], [Hornikx and Renterghem, 2017], [Ballou, 2008]. The claim the the crosswind effect refract the wave in the wind direction. Furthermore they claim that the effect is not linear in frequency. The author of [Ballou, 2008] indicate that the frequency dependency might be due to the directionality of the high frequency drivers.

2.2.4 Pressure impact

The effect of atmospheric pressure change is low compare to wind, humanity and temperature impact. The average attenuation from 4.0 kHz to 16.0 kHz with fixed temperature was 2 dB SPL while going from 54.02 kPa to 101.33 kPa. The atmospheric pressure then only have a negligibility impact is on sound and is generally not frequency dependent.

2.2.5 Ground absorption

2.2.6 Homogeneous speed equation

The following Equation 2.2 calculate the speed of sound based on homogeneous temperature and wind speed.

$$c = u \cdot cos(\theta) + c_0\sqrt{1 + t/t_0} \tag{2.2}$$

Where:

c	is the speed of sound	[m/s]
u	is the speed of wind	[m/s]
c_0	is the temperature at ... 331	[°C]
t	is the temperature	[°C]
t_0	is the reference temperature (273.15)	[°C]
θ	is the angle of wind with respect to the wave propagation	[°]

2.3 Inhomogeneous atmospheric conditions

The aim of this section is to analyses the sound wave propagation in a inhomogeneous atmospheric conditions. In an inhomogeneous atmosphere the pressure and speed are a function of position. By this fact, the modelling of sound wave is very complex and depend on verius variable such as temperature and wind speed. The analysis will be limited to constant direction or a moment. Therefore wind turbulence is a subject for it self and will not be covered in this section. The following sections will make a short introduction to the effect at inhomogeneous atmospheric conditions. As in the privuslu section, it will be based on far field condition and a plan wave.

2.3.1 Atmospheric refraction

When the speed of wind, the temperature and humanity is assumed to be homogeneous in the sound field, the sound is travelling in a strage path. Often this is not the case, the wind speed increases logarithmically with the hight from the ground to the geostrophic wind [Yang, 2016] and the temperature and humanity is inhomogeneous. The geostrophic wind in founded from approximately 1 km above the ground [Association, 2003]. In such situation the change of sound wave propagation is directly caused by the atmosphere temperature or wind gradient. This often result in a curved path of the sound wave and is defined as atmospheric refraction. For small distances, the atmospheric refraction have a spars effect on the sound traveling path, because the speed of sound is much higher than the change by the wind and temperature. Generally distance up to 100 m is often assumed to have no significant refraction effect [de Oliveira, 2012]. For distances larger than 100 m the refraction is assumed to have a significant impact specially when the source and resiver is close to the ground.

Temperature The refraction occure because the temperature and humanity will changes with respect to time along the day. The sun heats the ground, and when the sun set and the concert area is full of audience. The eath and audience radiate varm air, which make the air at a low hight warm, but the temperature at a higher hight cooler. As explained in section 2.2.2 the speed of sound depend on the temperature and therefore the speed of sound will in this situation decay with respect to hight and result in a upwards refraction. The following Figure 2.3 illustrate the phenomena when the temperature decay with hight.

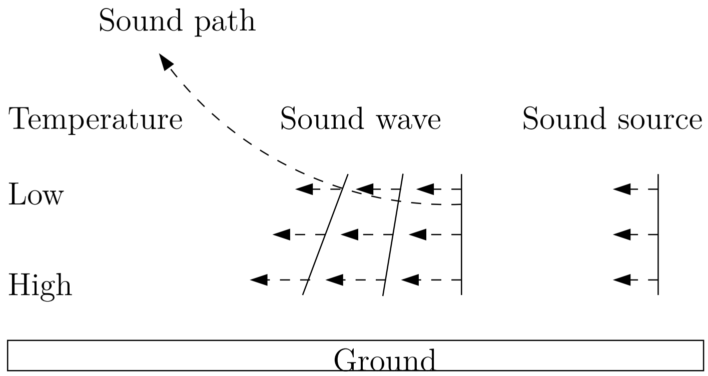

Figure 2.3: Wave refraction in inhomogeneous temperature

The sound refraction will be identically all around the source for a omnidirectional source with respect to temperature.

Wind With respect to wind speed, a concert area is often a protected area with for example barrier, stage and building and so thourgth. This blogage slows down the wind speed close to the ground, and from the nature it self the wind speed is often raise with respect to the hight. When the stage is playing in along with the wind the atmospheric refraction is down wards, where agenst the wind the atmospheric refraction will be downwards. The following Figure 2.4 shows the phenomena both against and with the wind.

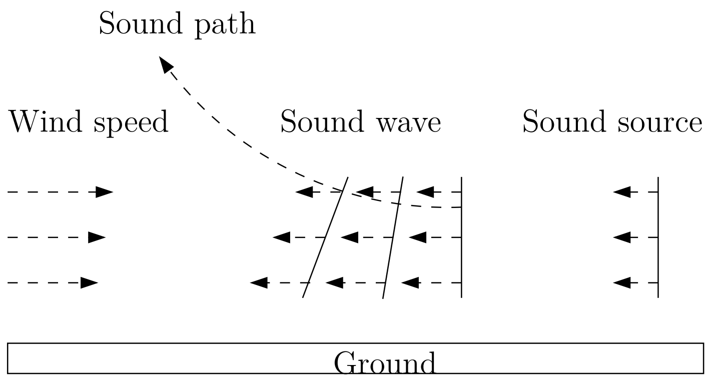

Figure 2.4: Wave refraction in inhomogeneous wind

Due to the refraction, the sound might propagate faster at the ground under the descriped condition. The consequence is a change for direction of the sound path bending upwards. This change of direction create whats called a shadow zone [Yang, 2016]. This is a zone where the sound pressure from the source is zero as shown in Figure 2.5

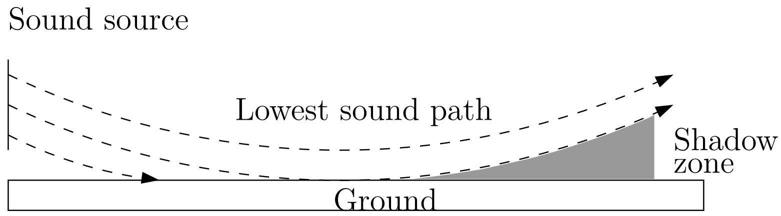

Figure 2.5: The figure illustrate the shadow zone ocourse from a upwards refraction. A line source speaker array contains of many couplet point sources. Every lowest sound path dashed line indicate the lower directional angle of one poins source in the line source array.

The refraction with respect to wind will depend on the wind direction. In Figure 2.5 the wind gradient is pointing in the opposite direction of the shadow zone . On the left side of the source the refraction will be downwards.

Oblique- and crosswind The effect of oblique- and crosswind on acoustical wave propagation in inhomogeneous atmospheric conditions is not studied with the knowledge of the author.

Turbulent

2.4 Atmospheric condition at a concert

A concert sound system is often calibrated in the midtle of the day when the stage is finished. The concert often starts in the evening and goes along to the late evening. at night the refraction goes the downwards direction

The concert area is dense packed with audience. The concert area might therefore be warmer nears the ground and cooles down with respect to the hight. This atmospheric condition refract the sound up in the air and not to the audience.

2.5 Calibration of sound system

This section analysis the calibration method, which is used by a selection of some Danish sound company. By expirence of the athor of this master projet, the hypothisis is that the sound system is calibrated in one point and the microphone is placed just in front of the Front Of House (FOH). The FOH is often a little tent, where the sound engineer control the sound system. The tent is only open in the direction of the stage and reflection might occore from the tent celling to the calibration microphone.

2.6 Sound pressure level measurement doing the concert

Chapter 3

Summary of Problem Analysis

Three effect of atmospheric conditions have been observed on the analysis, pure attenuation, lowpass effect and refraction effect

Chapter 4

Problem statement

Based on the knowledge founded in chapter 2 and the concluction drawn from **??** a problem statement can be made. For the rest of the project the following will be the focus.

Is it possible by signal possessing or physical ajustment with an line source array and an array of wind and temperature sensors to minimise the sound shadow zone created be atmospheric refraction. calculate the max distance before delay tower

4.1 Deimitation

The following delemitation is made for the search for a solution of atmospheric atmospheric.

Part II

Test Design

Chapter 5

Design

Part III

Results

Chapter 6

Results

Chapter 7

Discussion and conclusion

7.1 Conclusion

As stated in **??**, the main objective of this study is to assess the performance of a Bone Conduction (BC)-based communications channel, as compared with an Air Conduction (AC)-based one, in terms of intelligibility. In order to do so, it has been decided to design and perform a subject-based perceptual intelligibility test to obtain relevant data. However, extensive literature research about the matter of BC sound and the state of the art in transducers was needed beforehand. During the course of the project, the questions presented in **??** have mostly been answered, and all relevant data for the final intelligibility evaluation has been extracted. Based on relevant literature, the RadioEar B81 Bone Conduction Transducer (BCT) was chosen for all subsequent applications placed on the condyle. A key point of the project has been finding a way of linking the perceived levels from both the BCT and the Air Conduction Earphones (ACE) for the intelligibility test. In order to do so, a level matching routine has been developed, and although it does not provide exact data about excitation of the basilar membrane caused by the BCT, it provides a framework in which the inter-subject assessment of intelligibility can be performed by looking at the relative performance difference for each individual subject. The final decision has been made on the type of test to perform. Based on the potential application and the background of the project proposal, the Hearing in Noise Test (HINT) was deemed to be most suitable both in terms of obtainable results as well as practical feasibility. This test is based on short sentences, that are unknown to the test subjects.

After analyzing the results from the HINT, it can be concluded that there is a tendency, that the performance of BCT regarding intelligibility might be worse than the performance of ACE-based systems. With the obtained data, this tendency could not be shown to be statistically significant. A higher variance of the performance of subjects could be observed for the BCT. However, the difference in performance appears not to be so drastic, so that the difference does not render BCT as an invalid option for communication applications. The performance could likely be further increased by flattening the frequency response of the BCT with signal processing. Also a possibility of combining AC and BC in hybrid systems in order to increase the overall performance seems feasible as a subject of future research.

Part IV

Appendix

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