The Estimation of the Linear Sound Speed Profiles Under General Meteorological Conditions

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Introduction

In the case of medium and long ranges outdoor sound propagation, refraction due to temperature and wind gradients may increase (or decrease) the sound pressure due to a point source[1,2]. To fulfill the needs of practical outdoor sound propagation studies, it appears to be necessary to predict the sound speed profile (SSP) according to general meteorological informations.

The first part of this paper describes a practical method to estimate the sound speed profiles (SSP) under general meteorological conditions. The second part presents a method to estimate the corresponding linear SSP that can be incorporated in the heuristic acoustical model for outdoor sound propogation[3]. Finally, the third part of this paper gives comparisons between experimental and theoretical results.

1.0 Meteorological model

The sound speed profile between a source and a receiver could be expressed as a function of temperature, and wind characteristics. The exact determination of the wind speed and temperature profiles from general meteorological conditions is not possible. Using the surface-layer similarity scaling theory, it is however possible to obtain a good estimate of these profiles[4].

For this theory, it is necessary to evaluate *L*, the Monin-Obukhov length. This value depends mainly on the friction velocity and on the vertical heat flux at the surface. This last parameter is however difficult to measure and not easily available. To overcome this problem, a simple method to estimate *L* is proposed. This method use the relation observed by Golder[5] between values of Turner classes, the roughness of the ground and *L*.

2.0 Estimation of the linear sound speed profile

In a recent paper[6], an heuristic acoustical model for outdoor sound propagation has been presented. This model is an extension of the classical ray-theory that includes the effects of curved rays due to the refraction. This acoustical model assumes a linear sound speed gradient defined as:

$$c(z) = c(o)\,(1 + a\,z)$$

where a is the linear sound speed gradient, c(o) is the reference sound velocity on the ground and z is the height of the point. The assumption of a linear sound speed profile allows an analytical determination of the ray path parameters (travel time, angle of reflexion on ground, path length etc.)

The linear sound speed gradient *a* used in the acoustical model must be estimated from the SSP determined by the meteorological model. The method proposed is deduced from one used in radio communications[7]. Between a source and a receiver, the zone of space concerned with the propagation process is mostly defined by the first Fresnel ellipsoïd (Fig. 1). This is the zone of space where the path length difference between the direct path and any scattered path is lower than the half wave length.

$$\frac{\lambda}{2} = r_1 + r_2 - r$$

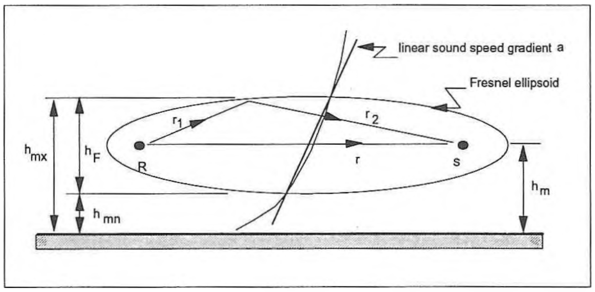

Figure 1 Schema of the the Fresnel ellipsoïd, the zone of space concerned with the propagation process.

The equivalent linear sound speed gradient is obtained by considering the mean of the real sound speed profile in the first Fresnel zone.

$$a = \frac{c(h_{mx}) - c(h_{mn})}{c(o)\,(h_{mx} - h_{mn})}$$

where $h_{mn} = h_m - h_F$

and $h_{mx} = h_m + h_F$

with $h_F = \sqrt{\frac{\lambda}{4}\left(r + \frac{\lambda}{4}\right)}$

(1) Thus, because the wide of the Fresnel ellipsoid (h_F) is function of the distance and of the frequency, the linear sound spreed gradiant *a* depends not only on the heights of the source and receiver, but also on the frequency and on the source and receiver.

3.0 Comparison with experimental results

To validate and determine the limitations of this approach, various acoustical and meteorological measurements of the noise emitted by strong and steady sources of an industrial plant have been done during the summer of 1993. These measurements were done during different days and at various periods of the days. The receiver's position considered was located at about 1 km of the sound sources. The data were analysed and show that there is an strong correlation between the increase of the SPL and of the linear sound speed gradient. Figure 2 shows the statistical distribution of the SPL measured during different periods and Fig. 3 shows these SPL as a function of the linear sound speed gradient.

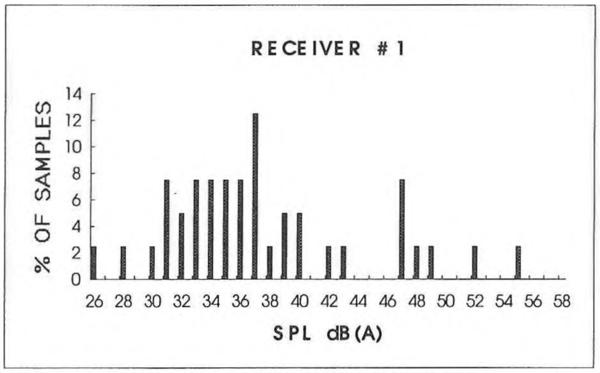

Figure 2 Distribution of the total Sound Pressure Level from two sources (320 and 440 Hz) of an industrial plant.

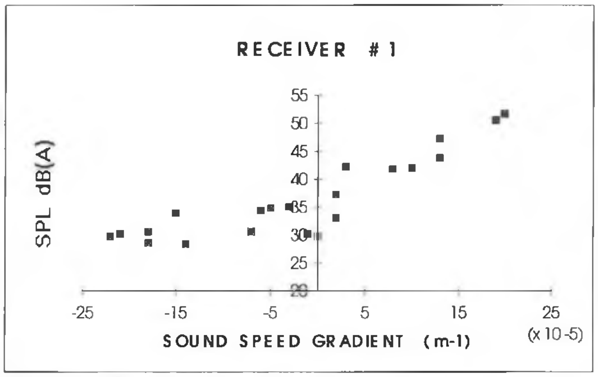

Figure 3 Sound Pressure Levels as a function of the linear sound speed gradient measured near an industrial plant (F=320 and 400 Hz).

To complete this analysis, the excess attenuation spectra (mean values, standard deviation and maximum values) measured at 2 089 m for 415 ground runup events[8] were compared to theoretical results. As the different meteorological conditions associated with these acoustical measurements were not known, mean values of linear sound speed gradient were used. The mean excess attenuation spectra predicted is in good agreement with the mean of the experimental results. Also the variations of the experimental data around the mean value can be explained by the variations of the various refraction conditions during the measurements.

Finally, it should be mentionned that, in combination with the heuristic acoustical model[6], this method gives a complet and practical scheme to predict outdoor sound propagation under various meteorological conditions, and only requires low computation time.

4.0 Conclusion

In this paper, a practical method to determine the linear SSP from general meteorological informations was proposed. In combination with a geometric ray acoustic model, a complete model for engineering purposes is obtained to predict variations of the SPL under different meteorological conditions. Comparisons with experimental results have shown that the general tendencies are well respected. From the experimental measurements, it was also observed that the heat flux conditions, function of the solar altitude and of the cloud cover, have an important influence on the increase of the sound pressure levels. Thus, the SPL's in the night period were statistically higher that those occuring during the day and the highest SPL have occured during the night when the wind direction was near the axis of propagation.

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