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A NOTE ON THE NEGLECT OF THE DOPPLER EFFECT IN THE MODELLING OF TRAFFIC FLOW AS A LINE OF STATIONARY POINT SOURCES

In many traffic noise prediction models the traffic flow is considered to be a line of stationary point sources, emitting the standard spectrum of a vehicle moving in a direction perpendicular to the line between observer and the vehicle. In practice, however, most vehicles will have a velocity component towards the observer which will result in a changed source spectrum because of the Doppler effect. In this article a formula is derived that makes it possible to predict the influence of the steepness of a spectrum on the L_{eq} of a traffic flow. It is shown that at a source speed of 100 km/h the Doppler effect can indeed be neglected.

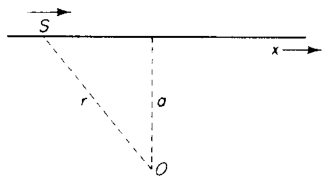

Figure 1. An observer O at a distance a from a line on which a source S moves with speed v. The projection of O on the x-axis is the zero reference point.

The situation under consideration is shown in Figure 1. A point source S is moving on a line with speed v. An observer O on a perpendicular distance a to the line and a distance r to S is present near the line. The frequency shift from f_0, the source frequency, to f, the frequency observed at O, can be written as

$$f = f_0/\{1 + vx/c(x^2 + a^2)^{1/2}\} \tag{1}$$

with a as indicated in Figure 1 and c the sound speed. According to reference [1] the equivalent sound pressure level L_{eq} can be written as

$$L_{eq} = 10 \log \left\{ \frac{1}{Tp_0^2} \int_{t_1}^{t_2} p^2 \, \mathrm{d}t \right\}, \tag{2}$$

with $T = t_2 - t_1$ and $p_0 = 2 \times 10^{-5}$ Pa. As $p(f)$ is related to the source power spectrum $W(f)$ by

$$p^2(f) = W(f) Z_0 / 4\pi r^2, \tag{3}$$

with Z_0 the impedance in air, L_{eq} can be written as

$$L_{eq}(f) = 10 \log \left\{ \frac{1}{Tp_0^2} \int_{t_1}^{t_2} \frac{W(f) Z_0}{4\pi r^2} \, \mathrm{d}t \right\}. \tag{4}$$

This can be rewritten as an integration over distance (see Figure 1) as

$$L_{eq}(f) = 10 \log \left\{ \frac{Z_0}{4\pi v p_0^2} \int_{x_1}^{x_2} \frac{W(f)}{x^2 + a^2} \, \mathrm{d}x \right\}, \tag{5}$$

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where x_1 and x_2 are the positions of the source at times t_1 and t_2. Because the apparent source spectrum $W(f)$ depends on the magnitude of the velocity component towards the observer, it is also dependent upon the position x along the line and can therefore not be removed from under the integral. To solve the integral in equation (5) some sort of approximation of W has to be made. As a first order approximation one can assume that W depends linearly on the frequency over a large interval around f:

$$W(f)=\alpha f+\beta. \tag{6}$$

By using equations (1), (5) and (6) the following expression can be given for the equivalent sound pressure level for frequency f (perceived by the observer) as a function of the frequency f_0, emitted by the moving source, the velocity of the source and the frequency characteristics of the source:

$$L_{eq}(f)=10\log\left[\frac{Z_0}{4\pi v p_0^2 T}\left\{\int_{x_1}^{x_2}\frac{\beta}{x^2+a^2}\,dx+\int_{x_1}^{x_2}\frac{\alpha f_0}{x^2+a^2+vx(x^2+a^2)^{1/2}/c}\,dx\right\}\right]. \tag{7}$$

According to reference [2] the solution of this integral is

$$\begin{aligned}L_{eq}(f)=10\log\Bigg[\frac{Z_0}{4\pi T a v p_0^2}\Bigg\{&\beta\left(\arctan\frac{x_2}{a}-\arctan\frac{x_1}{a}\right)\\&+\frac{\alpha f_0}{(1-v^2/c^2)^{1/2}}\left(\arctan\left(\frac{x_2 a}{(1-v^2/c^2)^{1/2}}\right)-\arctan\left(\frac{x_1 a}{(1-v^2/c^2)^{1/2}}\right)\right.\\&\left.+\arctan\left[\left(\frac{x_1^2}{a^2}+1\right)\left(\frac{c^2}{v^2}-1\right)\right]^{1/2}-\arctan\left[\left(\frac{x_2^2}{a^2}+1\right)\left(\frac{c^2}{v^2}-1\right)\right]^{1/2}\right)\Bigg\}\Bigg].\end{aligned} \tag{8}$$

Because in most situations the position of the observer is thus that $x_2=-x_1$, the last part of this equation is non-zero only for non-symmetrical cases. The part with β represents the solution as derived by Rathe [3] for a white noise spectrum, and the middle part with αf_0 takes into account the influence of the source speed and the steepness of the spectrum. In most cases the source starts at $x_1=-\infty$ and continues to $x_2=+\infty$ and equation (8) reduces to

$$L_{eq}(f)=10\log\left[(Z_0/4Tavp_0^2)\{\beta+\alpha f_0/(1-v^2/c^2)^{1/2}\}\right]. \tag{9}$$

This formula for the L_{eq} of a pure tone f can now be used to estimate, for example, the influence of the neglect of the Doppler term on the L_{eq} of a 1/3-octave band,

$$L_{eq,terts}=10\log\int_{f_1}^{f_2}10^{L_{eq}(f)/10}\,df, \tag{10}$$

with f_1 and f_2 the lower and upper cut-off frequencies, respectively. Combination of equations (9) and (10) gives

$$L_{eq,terts}=10\log\left[(Z_0/4Tavp_0^2)\{\beta(f_2-f_1)+\tfrac{1}{2}\alpha(f_2^2-f_1^2)/(1-v^2/c^2)^{1/2}\}\right]. \tag{11}$$

The error ε, caused by neglecting the $(1-v^2/c^2)^{1/2}$ term, can be written as

$$\varepsilon=10\log\left\{1+\frac{[1/(1-v^2/c^2)^{1/2}]-1}{[2\beta/\alpha(f_2-f_1)]+1}\right\}. \tag{12}$$

For $v=100$ km/h and $\beta/\alpha=0$, ε amounts to only 0·015 dB. Hence modelling a traffic flow as a line of stationary point sources does not introduce important errors in the calculated L_{eq} of that traffic flow. With regard to the spectrum shape it can be seen that the error vanishes for a flat spectrum ($\alpha=0$) and for steep spectra with high levels

($\beta/\alpha \gg 1$). It seems that the Doppler effect can safely be neglected in traffic noise modelling. Also the so-called convective amplification, i.e., the change in directionality of the sound source as a result of the velocity of the source, can be neglected [4]. The difference in sound pressure level (calculated in front of the source) between a moving source and an immobile source is, according to reference [4], 1·8 dB for $v/c = 0{\cdot}1$.

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