HYBRID IMAGE/ENERGY APPROACH FOR ACOUSTICAL PREDICTIONS OF INDUSTRIAL ROOMS

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INTRODUCTION

Several approaches may be used for acoustical prediction computations, among which is Sabine method, ray-tracing method, images method, or empirical methods. However, these methods are either too approximate or too complex to be easily implemented by hygienists, engineers, and other persons who work in the field of industrial noise. To compensate for this gap, a hybrid approach based on geometry acoustics and on energy acoustics has been developed. To make this acoustical prediction model easy-to-use, a Windows graphical interface has been created. The following article presents the acoustic model and the graphical interface which facilitates its use. Some results that have been obtained with the proposed model will be presented and compared to results obtained with standard methods.

1. Computation Method

The new method is based on Sabine method. It first consists in determining the contributions of the direct field and of the first reflections on the walls. It then distributes the residual energy that has not been considered in those contributions. According to Sabine's approach, the sound field at an point in a reverberant room corresponds to the combination of the direct field and the reflected field, that is :

$$Lp=Lw+10Log\,[1/(4\pi r^2)+4/R] \qquad (1)$$

where the term $4/R$ represents the contribution of the diffuse field, R is equal to $S\overline{\alpha}/(1-\overline{\alpha})$, where $\overline{\alpha}$ is the average absorption coefficient of the room. The contribution of the reflected field is based on the hypothesis that, in diffuse filed and steady state, the energy after the first reflection, that is $Wa = W(1-\overline{\alpha})$, must be in balance with the energy absorbed by all the walls, which, in diffuse field, is equivalent to[1]:

$$Wa = W(1-\overline{\alpha}) = <P^2> S\overline{\alpha}/(4\rho c) \qquad (2)$$

where $<P^2>$ is the sound field, S is the total surface of the room wall, and ρc is the air density and sound speed.

- Sabine's method of order n

If one determines not only the contribution of the direct field but also the contributions of the paths that have been subjected to a first reflection on each wall of the room, equation (1) becomes :

$$Lp = Lw+10Log\,[1/(4\pi r^2)+C_1+4/R_1] \qquad (3)$$

or

$$C_1 = \Sigma(Q_i/4\pi r_i^2) \qquad (4)$$

where C_1 represents the contribution of order 1, that is the sum of the contributions associated to i paths (r_i) that have been subjected to a first reflection on each m wall of the room. Those paths are balanced according to the absorption coefficient Q_i associated to the reflection on each wall.

The last term of eq. (3) corresponds to the contribution of the residual field, excluding the first reflection. Similarly to eq.(2), the residual field R may be evaluated from the balance between residual energy after the second reflection and the energy absorbed by all the walls, that is $Wa'=W(1-\overline{\alpha})(1-\overline{\alpha})$. By extension, knowing the contributions of the paths that have been subjected to 1, 2 or N reflections on each wall of the room, the sound level at a given j receiver may be evaluated with :

$$Lp(j)=Lw+10Log\,[1/(4\pi r_j^2)+C_1(j)+...+C_n(j)+4/Rn] \qquad (5)$$

where

$$Rn= S\overline{\alpha}/(1-\overline{\alpha})^{n+1} \qquad (6)$$

- **Determination of the contribution of order n, C_n**

The algorithm that was developed to determine the reflected paths on each wall and for each computation order uses the Borish[2] approach. This algorithm consists in determining the position of an image source through a wall using the normal of the wall and the position of the original source. When this computation is done for the m walls of the room, the process must be repeated using the position of the image sources as the original source, and so on. The number of potential Nbi image sources created for each order n becomes high :

$$Nbi= m^{(n-1)} \qquad (7)$$

The analysis of the contributions in relation to the computation order for different j receivers shows that the $Cn(j)$ contributions become relatively independent of the receiver's position as the order n increases. (figure 1).

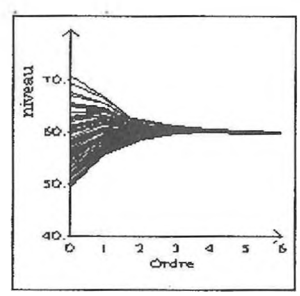

Figure 1 Contributions *Cnj* in relation to order n.

This result is explained by the fact that, for high reflection orders, the distances of the paths and their associated absorption coefficients $Qn(j)$ become relatively independent of the receiver's position. Combined with the fact that there are many reflected paths for each order and each position of receiver, the result is that the Cnj become independent of the receiver's position near order 5. This result corresponds to the fact that the reflected field is diffuse, and thus the Rn residual field becomes identical for all the receivers.

For rooms of complex shape, or when barriers are considered, some receivers will have different *Cn* contributions, even for higher orders, due to the fact that they are in a shadow zone in relation to walls or barriers. To take this phenomenon into account, residual energy at a *(j)* receiver is evaluated from the relation between the contribution received at order n at this *Cn(j)* receiver and the average contribution received at the other *Np* receivers :

$$Rn(j)= Cn(j) / CMn *4\ S/(1-\overline{\alpha})^{n+1} \qquad (8)$$

$$CMn=\Sigma Cn(j) /Np \qquad (9)$$

2. Graphical Interface

A user-friendly graphical interface under Windows environment allows to define or modify at any time the data that is necessary for modeling. The functionalities are grouped under 7 main menus, among which is *Room Construction*, a menu that offers tools to define the geometry and the acoustic parameters of the room.

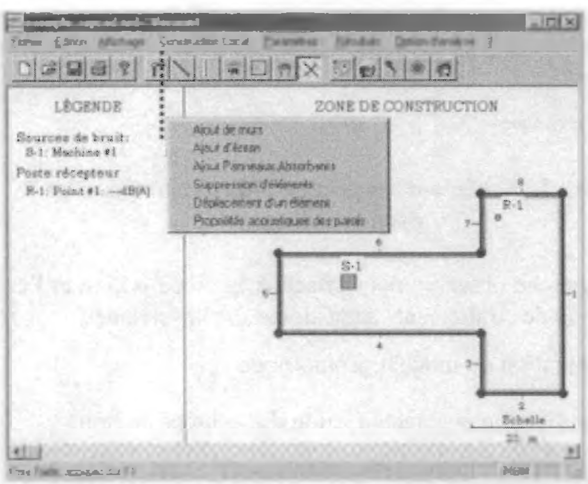

Figure 2 Main menu of the graphical interface

Furthermore, the user may, with the mouse, draw the lines to define the plan of the studied room. Some action buttons are also available to facilitate this construction and the definition of the acoustical parameters. For example, by clicking on a line that represents a wall of the room, the dialog box that allows to modify the acoustical parameters related to this wall will appear. Moreover, the user may put acoustic barriers or absorbing panels at certain specific points of the room.

3. Results

Besides the computation of the sound levels at specific points of the room, the model allows to obtain the noise map (isophone) of the room. Figure 3 compares, for an irregular shape room, the isophones obtained with the proposed model and the isophones obtained with the ray-tracing method[3]. Figure 3 gives 8 of the 64 paths that have been considered to calculate the sound level at R-1 point. Figures 3a and 3b show that the predictions are similar for both models, and that the absolute levels as well as the repartition of the sound field are respected everywhere in the room. However, with the proposed model, it takes less than one minute to obtain the noise map.

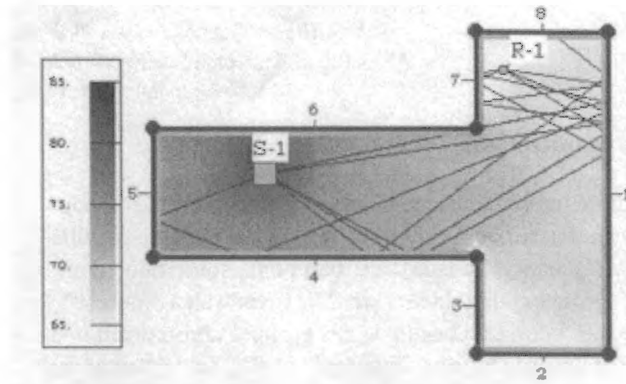

Figure 3a Isophone obtained with the proposed model

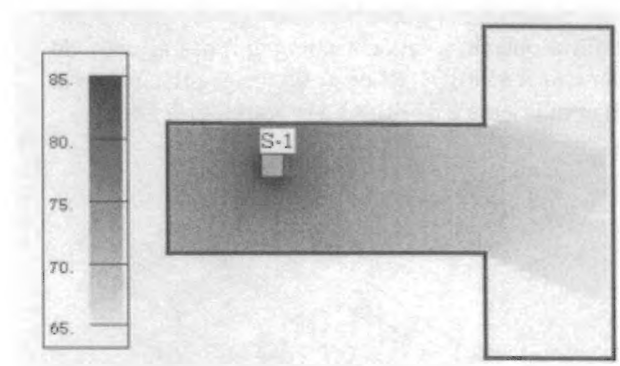

Figure 3b Isophone obtained with the ray-tracing method

4. Conclusion

A hybrid approach based on the image method and statistical energy has been developed. This approach, also called Sabine of higher orders, allows to consider the geometry and acoustical properties of each wall of irregular shape rooms. A user-friendly interface has been developed under Windows environment to facilitate the use of the model. The results obtained with the proposed model are similar to the ones obtained with other accurate methods, but the implementation of the proposed model is easier, and the computation time is shorter.

References

[1] Fundamentals of Acoustics, John Wiles & Sons.

[2] J.Borish. Expansion of the image model to arbitrary polyhedra, JASA 75,(6) p.1827-1836 (1984).

[3] Acoustique Prévisionnelle : Logiciel Rayscat, Les notes scientifiques et techniques de l'INRS, no 67 (1987).