MODELLING AIRCRAFT NOISE INSIDE DWELLINGS

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ABSTRACT

A numerical model for the prediction of aircraft noise inside dwellings has been developed; based on a decoupled method mixing integral, modal and geometric approaches. A special formulation for the effect of a balcony has been derived. Architectural effects such as projected roofs or nearby buildings have been analysed. Sound transmission is strongly affected by the angle of incidence of incoming waves. Measurements have been made in a real situation, using simple or double glazing windows. The proposed approach makes use of velocity fields on the windows measured with a laser vibrometer. Comparison between computations and measurements will be showed.

1 – INTRODUCTION

The annoyance due to aircraft noise near airports has become an increasing problem in recent years. Many studies have been carried in order to predict noise outside buildings, including many meteorological factors. However, few studies have been concerned by the prediction of aircraft noise inside dwellings. The purpose of this paper is to present a numerical tool capable of such a prediction, assuming a quiet atmosphere for any aircraft position. The computations are based upon the GRIM approach [1,2,4] which consists in interfacing a modal description of a reference unit -made of a room, a window and eventually a balcony- with a geometrical model for outdoor sound propagation [3]. Experimental validations have been made both in the vicinity of Orly's airport, near Paris, and in our laboratory using a laser vibrometer.

2 - THE GRIM APPROACH

Geometrical approaches can deal efficiently with outdoor sound propagation problems whereas integral representations can represent coupled vibro-acoustic problems. The GRIM approach has been presented in several papers and conferences [1,2,4] and an original field of application is considered in this paper. Applying the GRIM method to sound insulation problems consists in using, in the integral representation of an acoustical field, a complex Green function which is computed by means of a ray tracing program or the like. If we consider the case of an outdoor noise source at position *S* and a receiver point *M* inside a dwelling we first consider the reciprocal problem and write that the pressure at *S* due to a source at *M* can be written as:

$$P(M) = j\rho\omega\int_{S_V} V(Q).G_V(M,Q).dS(Q) \qquad (1)$$

where *V(Q)* is the velocity of the outer window pane S_V and $G_V(M,Q)$ is the Green solution between *M* and S_V when S_V is assumed perfectly rigid. G_V includes all outdoor surfaces. It is also assumed that the velocity *V* can be obtained from a decoupled problem consisting only of a room and a window. This has been numerically verified. In practice, *V* can be measured, using a laser velocimeter. It can also be computed by means of a modal approach or by a finite element program. This approach renders possible the study of complex situations with reasonable computation times. The estimation of V needs only to be carried once and a database consisting of sets of pre-collected spectra can be employed rapidly in different situations where only the estimation of G_V needs to be done.

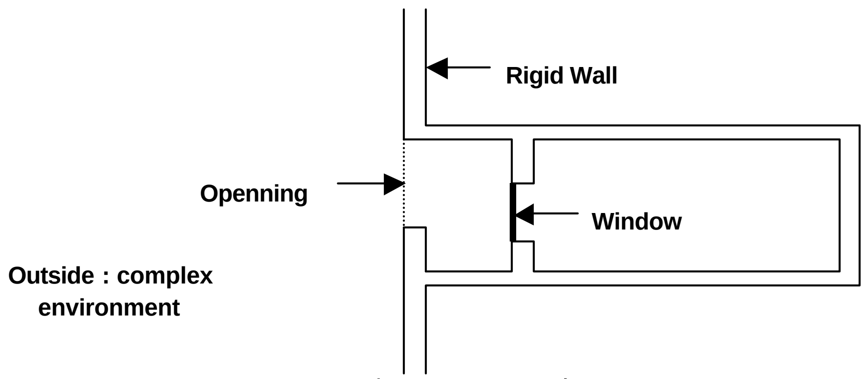

Figure 1 : General geometry.

Figure 2 shows in the 2D case of Figure 1 1/12 octave indoor sound pressure level either computed by a reference FEM/BEM program [5] or with the present approach.

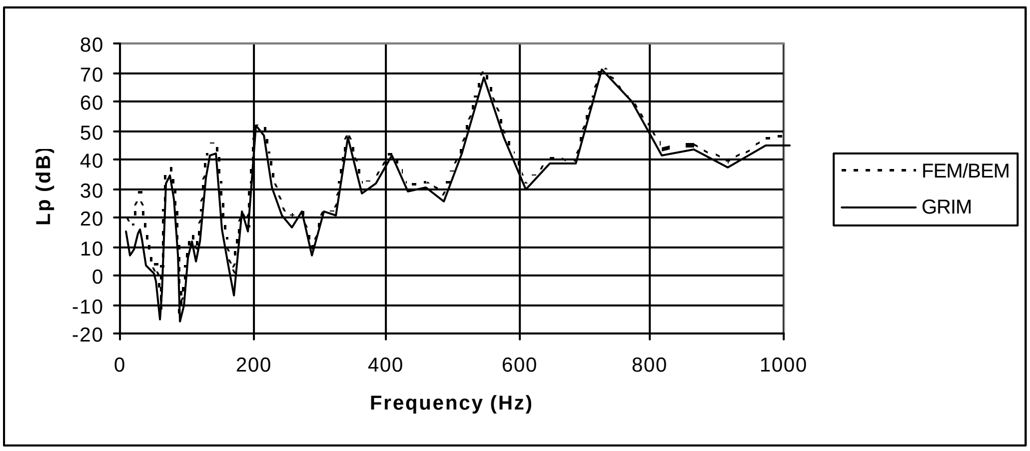

Figure 2 : Validation in a 2D situation

3 - GEOMETRICAL MODELS

Two different geometrical models have been developed to compute the Green functions either for 2 D, 2.5 D or 3D problems (RAYDIFF and ICARE). In ICARE, the 3D computation is based on an original ray tracing approach developed [3] at CSTB which considers beams made of 3 rays which will be sub-divided according to the geometry as the beams propagate between sources and observer points. This program takes into account both curved surfaces and diffraction edges using the Uniform Theory of diffraction.

4 - ARGOS

The computation of the velocities on S_V is made by a modal program named ARGOS. This program considers full coupling between rectangular plates and volumes. Several boundary conditions are included for the plate (any combination of Simply supported, Free or Clamped). Sound transmission through simple or double panels can be considered, either baffled or between volumes.

Figure 3 shows a comparison of computations made by ARGOS and the 3D FEM/BEM program CAVAMEFF, developed at CSTB [6], in the case of a double glazing excited by a point force. The good agreement validates ARGOS.

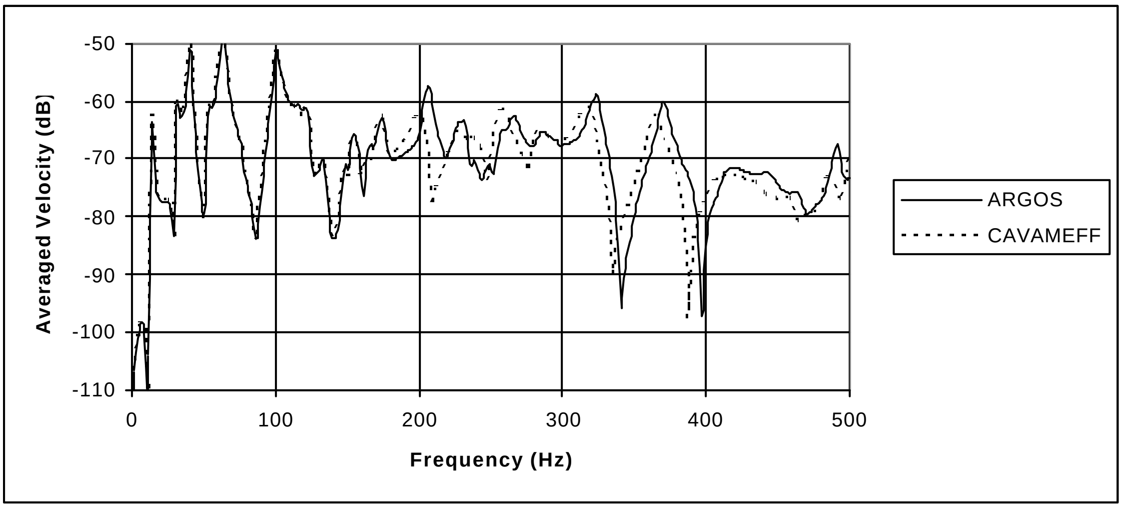

Figure 3 : Validation of ARGOS for a double 10-10-4 glazing. Point velocity on opposite glazing facing the excitation.

Furthermore, ARGOS contains a dedicated module to model balconies, wich is an extension of Kropp model [7], so that the full room + window + balcony can be computed precisely in order to report the integration surface S_V at the opening of the balcony. In this manner, the ray tracing calculation does not have to be carried inside the balcony, where it is of moderate precision. In [4], it is showed that very good results can be obtained by this approach.

Both 2D and 3D calculations have been carried. In order to verify the validity of 2D calculations Figure 4 compares both types of computations, where the difference of sound pressure level inside and outside a window, in the same perpendicular plane, is plotted. Although not quite identical, a significant similarity can be observed which shows that 2D calculations can be very informative.

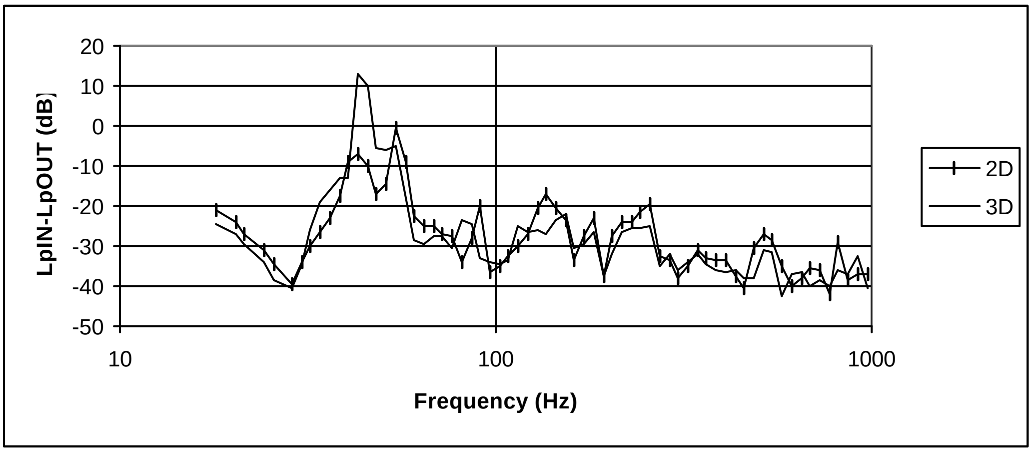

Figure 4 : 2D-3D comparison

5 - MEASUREMENTS

With the participation of ADP (Aéroports De Paris) measurements have been inside a house placed at the end of runways, close to a measurement station which gives the plane trajectories and enables temporal adjustement. This house was directly under landing planes. The measurements have been at one external point 2 m away from the facade and at 3 points inside a room. Three types of windows have been tested. The velocity of the window has been measured in our laboratory using a laser vibrometer where the different windows have been installed in a room having the same dimensions than the first one and similar reverberation times and where a loudspeaker is successively placed at the 3 receiver points. Figure 5 shows the geometry of the room, window and measurement points.

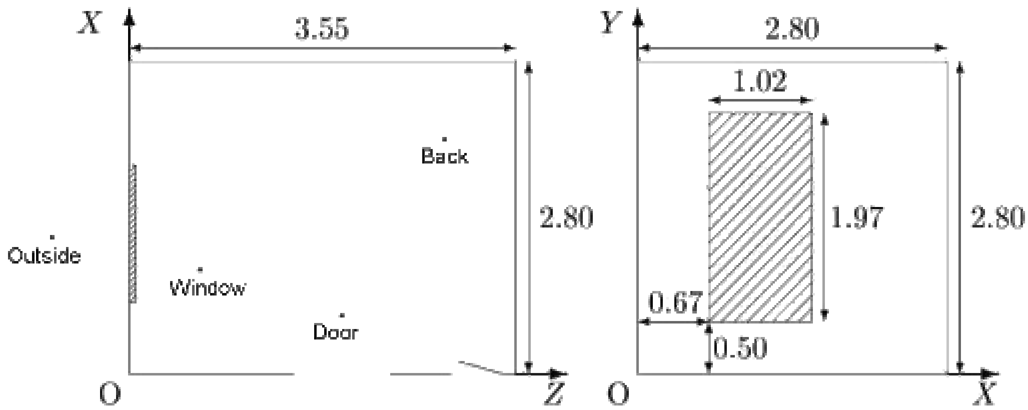

Figure 5 : Room configuration.

Therefore, we have three different results

- On site measurements near Orly's airport
- Computations mixing the laser velocimeter measurements and the GRIM approach
- The GRIM method using ARGOS computation of the velocity

Figure 6 shows a comparison, for a simple glazing, of the sound pressure level difference between the external point and the mean indoor value.
A good agreement can be observed and improved results can probably be achieved using more precise global losses, in particular near the critical frequency.

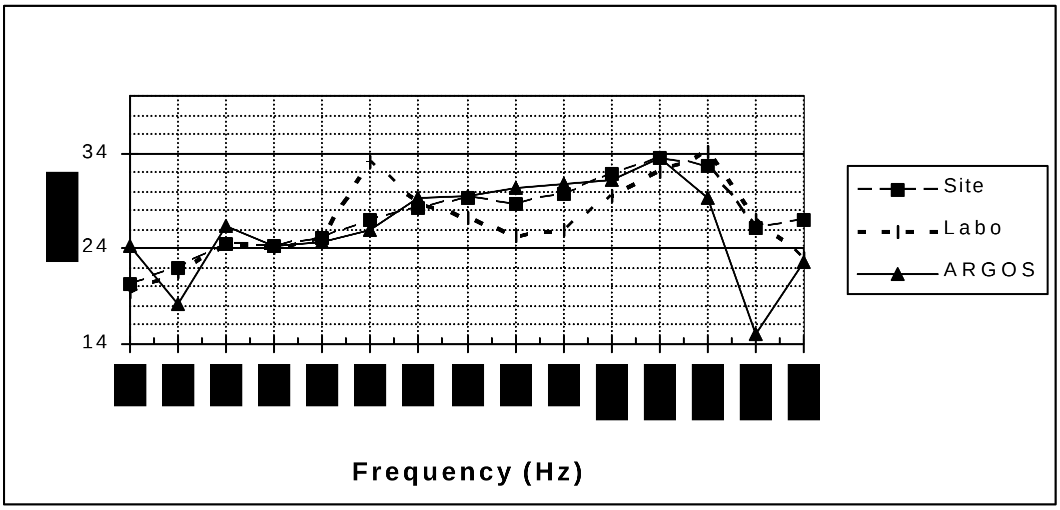

Figure 6 **:** Validation in the case of a single glazing.

Figure 7 represents the dependency of the sound reduction index on the angle of incidence of incoming waves, for the 3 different windows considered (simple glazing, ordinary double glazing and improved double glazing) obtained from the laser measurements of the windows. A strong angular variation can be observed, which suggests that traditional diffuse field measurements of *R* is not appropriate to evaluate the isolation of windows in an airport situation. It also suggests that dedicated facade elements could be designed for airport environments.

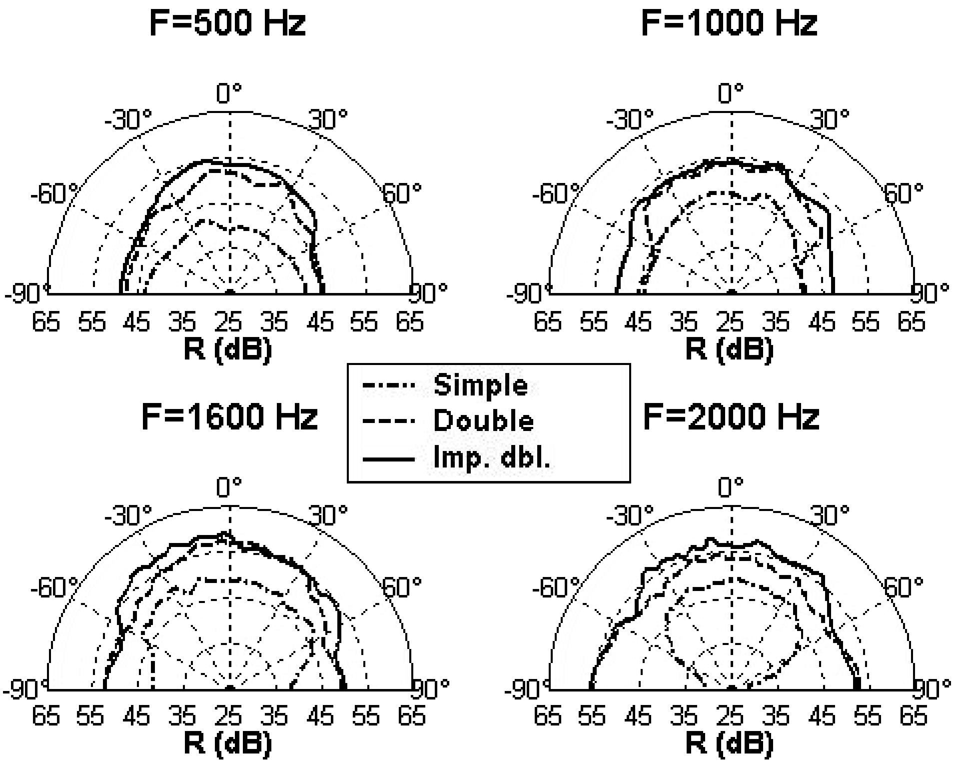

Figure 7 : Measured directivities.
Simple Glazing Double glazing Improved double glazing

CONCLUSIONS

New tools are required to efficiently model noise around airports. The GRIM approach shows good promise for the assessment of noise inside dwellings and can therefore be considered as a new step towards a general prediction model.
The good agreement between simulation and measurements in the case of single glazing shows the potential of the GRIM approach when applied to airport noise, in particular to estimate directivity effects on sound transmission through facade elements such as windows. The extension of such calculations to other facade elements will be done in a close future.

In the case of double glazing, the computations made with ARGOS are not satisfactory since the omission of peripheral links such as due to the frame leads to an overestimation of sound insulation. Such peripheral transmission is known to become important in the higher frequency range where SEA can be employed to complete the model [8,9]. Such developments are also under way. Other measurement facilities such as phonoscopy [10] –which is an holography-like technique- have been showed more precise and will probably be preferred in the future to laser measurements which suffer from an insufficient dynamic.

ACKNOWLEDGEMENTS

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