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An accelerated BEM for simulation of noise control in the aircraft cabin

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ABSTRACT

In this paper passive noise control in the aircraft cabin by using nanofibre textiles is investigated. The acoustic performance of the aircraft cabin under different noise sources and with various seat textiles is tested experimentally and analysed numerically. The numerical results are obtained by means of the three-dimensional Boundary Element Method (BEM) accelerated by the Adaptive Cross Approximation (ACA) and the Generalised Minimum Residual (GMRES) solver. Some numerical analysis are carried out in order to assess the accuracy of the numerical model in comparison with experimental results. A new nanofibre textile with excellent acoustic properties in the low frequency range is modelled and its performance assessed. Finally, a new shape of the seats' headrest, aimed at reducing further the noise disturbance, is proposed and analysed.

1. Introduction

The interior noise of aircraft cabin is an important concern due to its influence on passenger comfort and many researchers have investigated the best way to soften it (see for instance [5,9,14,16,17]). In order to reduce the noise, the designer must pay close attention to the response of the cabin from various acoustic sources. The complex shape of the cabin does not allow for an analytic solution. The mathematical resolution becomes more difficult when the designer applies acoustically absorptive materials not equally distributed on the cabin surface. There are many techniques available for modelling interior sound fields, including modal expansions, method of images, finite element (FEM) and boundary element (BEM) methods. The modal expansion method [8,13] is based on the analysis of the acoustic motion in terms of the normal modes of the enclosure. A good approximation in the interior can be obtained by using the acoustic modes for the rigid wall enclosure. Such a solution is not correct in the region near the boundaries. The FEM and the BEM [1,18] are both based on the discretisation of the Helmholtz wave equation for simple-harmonic waves. Regarding internal problems, the main difference is in the dimension adopted: FEM requires the discretisation of the entire volume under analysis whereas BEM meshes the boundary only. For external (i.e. infinite) problems BEM is capable to automatically satisfy the Sommerfield radiation condition without any domain discretisation. An application of BEM to nonlinear acoustics is given in [12].

Many papers have dealt with the computation of the approximate solution of the Helmholtz equation by FEM and BEM. On this regard the BEM seems to be more efficient particularly in 3D and when coupled with fast procedures such as Fast Multipole Method (FMM) [15] and Hierarchical Matrix format plus Adaptive Cross Approximation (ACA) approach [2]. In [7] an edge-based smoothed FEM approach for analysing acoustic problems is proposed in order to overcome the inaccuracy in the FEM solution with increasing wave number, i.e. the numerical dispersion errors. In [6] a cost comparison between BEM and FEM in acoustics is performed, but the comparison does not keep into account the recent improvements of BEM in conjunction with fast procedures such as FMM and ACA. There is a large number of papers concerning the application of BEM to 3D and 2D acoustic fields. Many references can be found in [18]. A BE/FE method to reduce the interior noise in the aircraft cabin is developed in [4] where the structure is dealt with FEM and coupled to the acoustic cavity modelled by BEM.

This paper presents some results obtained in the project "Smart tEchnologies for stress free Air Travel (SEAT)" under the 6th Framework Programme. The main goal of the paper is to numerically investigate the acoustic performance of a new textile material which was developed in the project. Such a textile is a nanofibre web with excellent absorptive properties in the frequency range 200–1000 Hz and it can be used as upholstery to reduce the noise in the aircraft cabin. All the numerical results are obtained by direct BEM and they are given in terms of pressure/velocity on the boundary. As the corresponding governing matrix is non-symmetric and fully populated, the numerical solution would be

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(a) (b)

Fig. 1. Experimental mockup. Internal views.

extremely time consuming. In the present paper the generation of the governing matrix and of the right-hand side vector is sped up by the ACA approach whereas the resolution of the system of equations is accelerated by the GMRES. The value at any internal point can be determined in the post-processing step on the basis of the knowledge of the solution on the boundary. The adopted elements are linear of quadrilateral/triangular type and the mesh is set in order to have 8–10 elements per wavelength. The numerical experiments are aimed at investigating the reduction of noise level inside the aircraft cabin which may be obtained by adopting new nanofibre textiles and different headrest geometries. The geometry under investigation coincide with an actual aircraft cabin. The absorbing properties of the panels of the cabin are determined on the basis of both the scientific literature [3] and some experimental results obtained by Acusttel (one of the partners of the project). The included numerical results have two goals: 1) to recover the experimental tests, 2) to probe the influence of new nanofibre textiles and headrest geometries on the noise control.

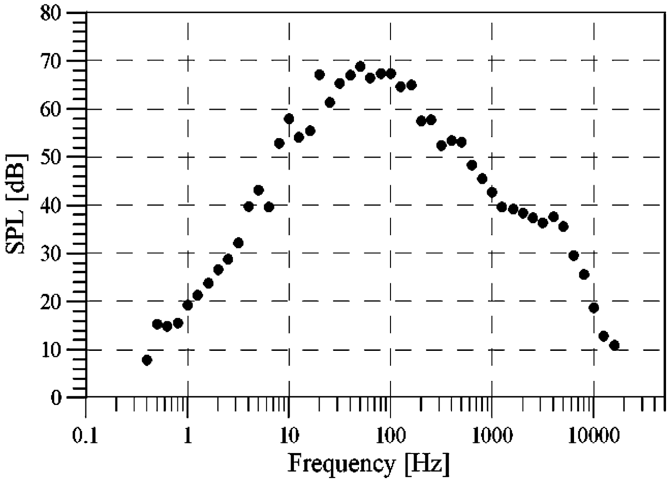

Fig. 2. Experimental signal spectrum – takeoff.

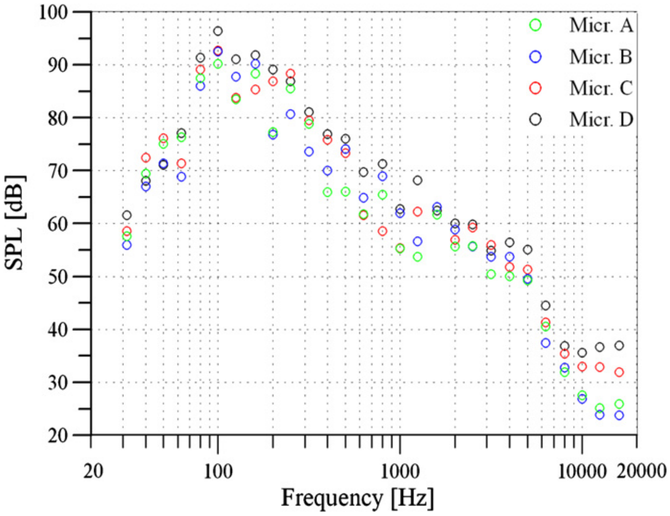

Fig. 3. Experimental results at the microphones – takeoff noise.

2. The experimental test

The numerical model was first tested by some experimental results obtained at the laboratory of Thales (Toulose, France). An aircraft cabin mockup (1/1 real scale – see Fig. 1) was set up and subjected to different acoustic sources reproducing the internal noise produced by typical flight operations. Some microphones were also located in order to measure the sound pressure level (SPL) in proximity of the passengers' ears. The experimental source was obtained by a dodecahedral speaker located in the middle of the corridor, 0.37 m from the rear plane and 1.42 m from the floor. Such a type of speaker was necessary in order to create a diffuse acoustic field inside the cabin. The speaker was modelled as a monopole in the numerical model.

The acquisition system, including microphones, analyser and wires, is of class I, i.e. the most precise possible. The sample frequency was 51 200 Hz and the acquisition was real-time and simultaneous in several microphone positions. Finally, the microphone calibration was checked before and after the tests.

Four microphones (two of them are visible in Fig. 1(a)) were positioned in order to measure the SPL.

The experiments were performed with different acoustic signals, i.e. with three signals reproducing the noise which occur internally during the takeoff, the landing and the cruise conditions. In other words, first the noise arising inside the aircraft cabin during three different typical flight operations was recorded, then, it was suitably reproduced by using an internal speaker located in the corridor of the cabin.

The spectrum signal referred to the takeoff is given in Fig. 2. In most applications the signal frequency content (or the frequency spectrum) is investigated. There are two primary reasons for obtaining frequency information about a signal. First, the response of the ear and the sensation of sound in humans is strongly dependent on the frequency. Second, the physical processes of sound emission, propagation, diffraction and transmission are all frequency dependent.

The experimental results detected at the microphones are depicted in Figs. 3–5 where the position of the four microphones (A, B, C and D) is given in Table 1 (in millimetres and with ref-