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LOW-FREQUENCY ACOUSTIC TRANSMISSION OF HIGH-SPEED TRAINS: SIMPLIFIED VIBROACOUSTIC MODEL

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This paper deals with the development of a numerical model describing the vibroacoustic behaviour of high-speed train coaches in the low-frequency range. This model which has been developed at the SNCF aims to improve the acoustic comfort of the passengers. This project has provided an overall view of the main physical phenomena occurring within a coach. Therefore the model has been developed using a simplified theoretical approach. Initial hypotheses and the main features of the model are then described. The different stages of the validation tests are discussed and a typical example of the usefulness of this tool is provided. Finally, further developments of the software are presented.

1. INTRODUCTION

For many years, SNCF has been concerned with the improvement of the acoustic comfort for passengers. This objective is generally in conflict with the increase of speed or the reduction of the weight of the structure. Thus, it appears essential to take acoustic constraints into account in the specifications for new rolling stock. In order to reach this goal, a research programme for double-deck high-speed trains were defined. It includes the development of two numerical models of the vibroacoustic behaviour of the coaches; a SEA model for high frequencies and a semi-analytical modal approach (CAPHCA) for low frequencies (below 200 Hz). These models have to satisfy the following requirements:

- modelling a whole coach,
- considering the fluid–structure interaction,
- enabling the main noise transfer paths through the structure to be characterized,
- taking into account aeroacoustic sources (stochastic and harmonic).

In this paper, mainly the low-frequency model will be discussed.

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2. DESCRIPTION OF THE MODEL

2.1. AN OVERVIEW

In order to fulfil the previous specifications, different scientific problems have to be treated.

The first concerns the noise transmission through a large and complex structure. It leads to the adoption of a compromise between the accuracy of the geometrical and mechanical description of the system and the necessity to maintain a global approach. Such a constraint avoids the development of a model based on FEM or BEM and requires some simplification before solving the vibroacoustic system.

Secondly, attention is focused on the importance of windows in the acoustic transmission of the coach sides. The model has to allow the effective influence of an inclusion in an homogeneous structure to be evaluated.

Lastly, information regarding the aeroacoustic excitations on a TGV coach under operational conditions is provided either by classical theoretical models (e.g. CORCOS model for the Turbulent Boundary Layer) or by measured databases (map of pressure fluctuations on the coach body). The numerical tool has then to be self-adapting towards input data.

Moreover, as both harmonics and stochastic excitations are involved numerical techniques have to be adapted for random analysis.

Consequently, it was decided to develop the following simplified vibroacoustic model:

The coach is assumed to be a parallelipipedic structure. The internal fluid volume can be split by a panel (in the case of a double-deck TGV). Each panel is considered to be an independent vibrating plate which may contain heterogeneities (windows).

The basic vibroacoustic problem can then be defined and solved: this is the acoustic response of a rectangular cavity backed by heterogeneous plate (see Figure 1).

The resolution of this basic system for all the panels, combined with the application of a superposition law, allows the reconstruction of the real acoustic ambience in the coaches.

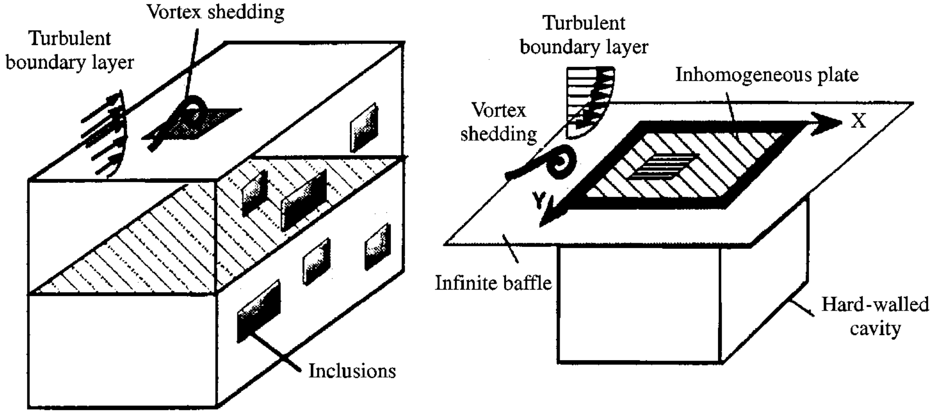

Figure 1. Diagram of the CAPHCA model.

All calculations are performed in the frequency domain. Linear behaviour is assumed and light fluids hypothesis is used. A semi-analytical modal method is used to describe on basic system. The internal fluid and vibrating panel subsystems are expressed on their own modal basis. A Rayleigh–Ritz approximation is made for the structure and a classical integral formulation is adopted to compute the cavity acoustical response.

2.2. SPECIFIC FEATURES OF THE MODEL

2.2.1. *Concerning the structure*

Each panel of the coach is defined as a heterogeneous and orthotropic thin plate. The master structure is designed as a multilayered material (including transverse shear stresses). The heterogeneities are monolayered but take into account the double-glazed windows acoustic effect: each pane is described separately; the exterior is perfectly embedded in the master structure and the interior one is elastically attached at its boundaries. The enclosed fluid is considered as a uniform surfacic stiffness added to panes stiffness.

The use of a mechanical equivalent law (conservation of the flexural inertia) is required to transform the mechanical characteristics of stiffened panels or more complex cross section shape panels into input data for the software.

2.2.2. *Concerning the internal volume*

The effect of interior fittings and covering of sides are modelled only through their absorbent effect; a frequency-dependent damping coefficient is achieved from the measurement of reverberation time.

The disturbance induced by the dynamic behaviour of this equipment and its spatial effect on the hard-wall cavity modes are neglected.

3. VALIDATION

CAPHCA has been tested on a section of a TGV Duplex. This section was 4·30 m long. Its structure was exactly the same as the structure of a TGV Duplex coach between bogies. Each extremity of the train section was hermetically closed with two heavy rigid panels. An insulated seal was used to increase the airtightness between the panels and the aluminium structure. The train section was excited acoustically. Four loudspeakers and a noise generator were used to reproduce the noise around a TGV Duplex running under normal operating conditions. The spectrum of the excitation noise was controlled using eight microphones placed around the train section. The mean sound pressure level (SPL) within the train section was measured with six microphones (three microphones in each section).

The first measurement was performed with an empty train section without seats, carpets, etc. The corresponding numerical model was created with CAPHCA. Windows were taken into account in each lateral panel. The SPL was computed in both spaces and compared with the measured value from 0 to 250 Hz. Simulation results agree with measurements from 0 to 250 Hz except for some pure tones where discrepancies can be observed. When analyzing the computed contributions of each plate, differences can be seen in the frequency range where the energy is transmitted mainly through the roof and the floors. Therefore, improved panels are required.

To take into account seats, carpets and other fittings-, a second measurement was performed using a fitted out train section. These fittings were not considered in CAPHCA model. Consequently, the fluid damping of the spaces was modified according to the measurement of the reverberation time. Comparisons between computed and measured SPL has validated this approach of taking into account the coach fittings.

These comparisons have shown that CAPHCA is able to predict the main trends of the noise transmission within a typical train prototype section. In next section, the validation of the model on the real case of a TGV, under operating conditions, will be discussed.

4. THE TGV-DUPLEX CASE

Measurements were performed in a TGV Duplex travelling under normal operating conditions. The boundary layers around the floor, the windows and the roof were characterized using wall pressure microphones. The SPL within a coach has been measured with several microphones.

The complete structure of the TGV Duplex was modelled in CAPHCA. The fluid damping was calculated according to the measured reverberation time.

The structure was only excited by the floor, the lateral panels and the roof boundary layers. Wall pressure measurements were used to define and tune the CORCOS model in CAPHCA [1, 2].

The simulated and the measured SPL within a coach have been compared for both floors and several speeds. SPL in the upper floor are shown in Figure 2 (train speed: 300 km/h).

Shapes of the measured and computed SPL were similar between 0 and 130 Hz. From about 130 Hz, the computed SPL was lower than the measured SPL. Furthermore, experimental data have highlighted the presence of a peak at around 140 Hz which was not predicted by the model. The differences between experimental and numerical results were probably due to the incomplete excitation of the structure; only boundary layers were taken into account and rolling noise or mechanical excitation were not considered.

Contributions of the structural parts to the noise within cavities were also computed. The energy was mainly transmitted through the roof from 0 to 50 Hz. In the frequency bands from 50 to 250 Hz the energy contributions of the other parts of the structure were similar.

The measured and computed SPL at the first floor are quite different. Close to the rails, the mechanical excitation seemed to be very important. The boundary layer did not generate all the acoustic energy transmitted into the coach.

These measurements have validated CAPHCA model by correctly predicting the SPL within a coach. However, as the results are excitation dependant, improvements of the excitation characterization are necessary.

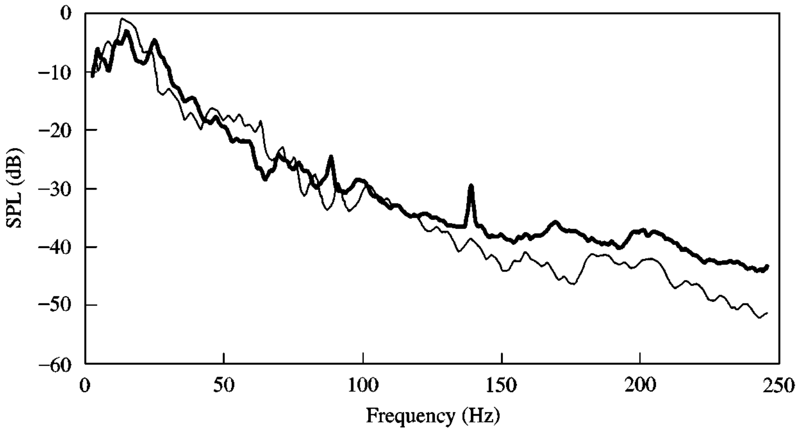

Figure 2. Measured and computed SPL in the upper floor of a TGV Duplex bold line: measured values, solid line: computed values.

5. CONCLUSIONS

The SNCF has developed a numerical model to predict the SPL within coaches. To define the contribution to each plate to the acoustic energy inside the cavity, a superposition method has been utilized. Using a train section and a real TGV Duplex, measurements have been conducted in order to validate the numerical model.

Experiments have shown that CAPHCA is able to predict the SPL evolution with respect to the frequency. Nevertheless, some improvements are necessary. For example, the dependence of the damping coefficients with respect to the frequency should be considered. On the other hand, some coach structures could not be modelled as simply supported plates. Boundary conditions may be modified to improve the model. Furthermore, stiffeners or panel curvature should be better taken into account.

In all cases, the excitation characterization is the most important parameter. All the main excitations must be considered (aerodynamic excitations, mechanical and airborne excitations generated by the wheel–rail interaction).

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