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SIMULATION OF THE TBL INDUCED VIBRATIONS OF A PLATE USING VIRTUAL SOURCES

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ABSTRACT

Finding an alternative to common test means (reverberant chamber, wind tunnel facilities, in-situ measurements, etc.) is of particular interest to the transportation industry (automobile, aeronautics, etc.) for the reproduction of the vibroacoustic response of structures under random excitations such as the diffuse acoustic field or the turbulent boundary layer. In this paper a method of achieving this goal using a single acoustic source and the synthetic array principle is proposed. To assess the validity of this method, an academic case study consisting of a simply supported thin aluminum plate under turbulent boundary layer excitation is presented. The vibroacoustic response of the plate is determined with the proposed process and compared to results from random vibration theory and direct measurements in an anechoic wind tunnel facility. This comparison shows good agreement between the proposed approach and both the theoretical and wind tunnel results.

1 INTRODUCTION

The experimental characterization of structures under random excitations such as the diffuse acoustic field (DAF) and the turbulent boundary layer (TBL) is of great interest to the transportation industry. However, the test facilities used (reverberant chamber for the DAF and anechoic wind tunnel/*in-situ* tests for the TBL) can sometimes be complex and costly. Moreover, the results obtained for a given structure can be very different from one facility to another even though the same setup is implemented. In this paper an alternative method is proposed and aims at simulating the vibroacoustic response of structures under these random excitations independently of the environment. This paper is organized as follows: first the proposed approach is briefly described. Secondly, the theoretical background on the vibroacoustic response of a simple structure under random excitation is given. Finally, some results are presented.

2 PROPOSED APPROACH

The experimental reproduction of the TBL induced vibrations using an array of acoustic sources has been theoretically shown some decades ago. But due to technical limitations, this method could not be experimentally validated back then. Since 2000, many researchers have addressed this problem using various approaches. Maury, Bravo, Elliott and Gardonio [1–4] have widely discussed the reproduction of a TBL excitation using an array of loudspeakers. This method works well when it comes to the reproduction of a DAF excitation but due to the limited number of sources in the array, it fails to simulate the wall-pressure fluctuations of a subsonic TBL excitation because of the high wavenumbers involved. In order to circumvent this limitation, a denser array of sources must be used. This is achieved by relying on the synthetic array principle which describes the effects of a full array of sources as the sum of the effects of each source. A single acoustic source is spatially displaced to different positions thereby virtually creating an array of sources.

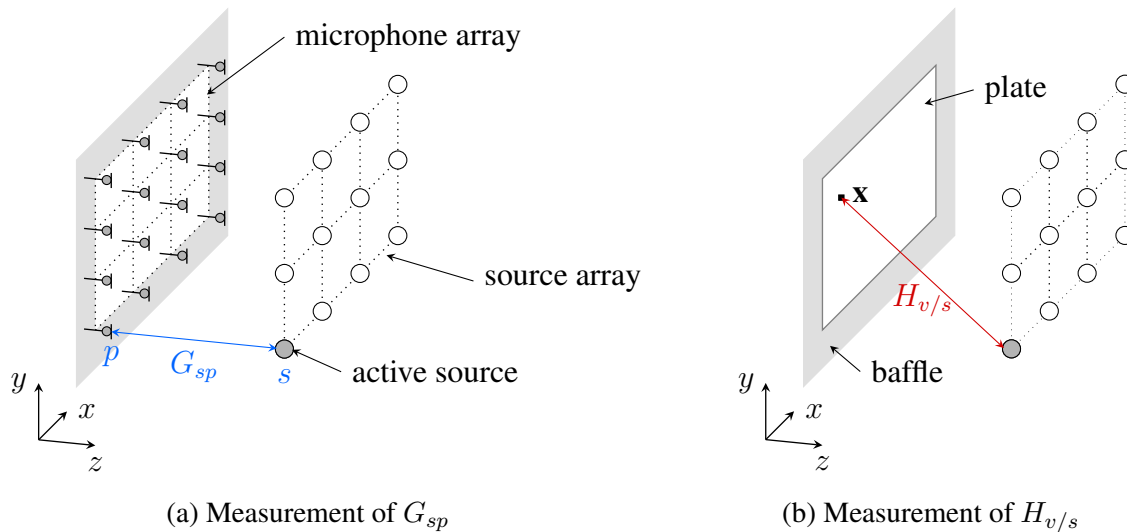


Figure 1. Problem geometry and parameters.

The proposed approach is based on the mathematical formulation of the problem in the wavenumber domain. This formulation is used because it allows an explicit separation of the contributions of the excitation *via* the wall-pressure cross-spectrum density (CSD) function from those of the vibroacoustic behavior of the structure *via* the sensitivity functions. Given a target pressure field $p(\mathbf{k}, \omega)$ consisting of wall-pressure plane waves of wave-vector $\mathbf{k} = (k_x, k_y)$, there are three main steps for the reproduction of this target pressure field using the synthetic array principle:

1. Characterization of the acoustic source: measurement of the transfer functions (G_{sp}) between source positions s and observation points p on the plate (microphones), see Figure 1a.
2. Computation of the source amplitudes Q_s at each position by inverting the equation below:

$$\sum_s Q_s(\mathbf{k}, \omega) G_{sp}(\omega) = p(\mathbf{k}, \omega) \quad (1)$$

3. Synthesis of the target pressure field on the plate surface by adding up the effects of the source at each position and simulation of the vibroacoustic response in a post-processing step.

3 SIMULATION OF THE TBL INDUCED VIBRATIONS OF A PLATE

3.1 Principle

Let us consider a simple test case consisting of a baffled and simply supported aluminum plate with the following dimensions: $480 \times 420 \times 3 \text{ mm}^3$. The auto-spectrum density function of the flexural velocity response noted $S_{vv}(\mathbf{x}, \omega)$ at some point \mathbf{x} of the plate under random excitation is approximately given in the wavenumber domain by the following equation [5]:

$$S_{vv}(\mathbf{x}, \omega) = \frac{1}{4\pi^2} \sum_{\mathbf{k} \in \Omega_{\mathbf{k}}} |H_v(\mathbf{x}, \mathbf{k}, \omega)|^2 S_{pp}(\mathbf{k}, \omega) \delta \mathbf{k} \quad (2)$$

$H_v(\mathbf{x}, \mathbf{k}, \omega)$ is the sensitivity function which corresponds to the vibration response of the structure to a wall-pressure plane wave of wave-vector \mathbf{k} and $S_{pp}(\mathbf{k}, \omega)$ is the pressure CSD function that describes the excitation.

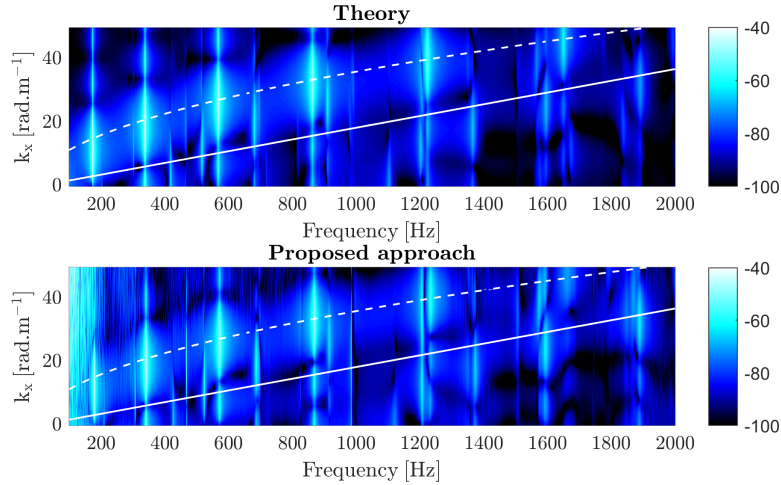


Figure 2: Squared value of the sensitivity function $|H_v(\mathbf{x}, \mathbf{k}, \omega)|^2$ (dB, ref. : $1 \text{ m}^2 \text{ s}^{-2}$) along k_x (for $k_y = 0$). Flexural wavenumber k_f (dashed line), acoustic wavenumber k_0 (continuous line).

Assuming that $S_{pp}(\mathbf{k}, \omega)$ is known, only the experimental measurement of the sensitivity functions of the structure is required in order to determine the response of the structure to the considered excitation by post-processing. The sensitivity functions of the structure are determined as follows: first the transfer functions between the different source positions and a point \mathbf{x} of the plate are measured. This transfer function between one source position s and the point \mathbf{x} is denoted $H_{v/s}(\mathbf{x}, \omega)$, see Figure 1b. Second, after the source amplitudes Q_s have been determined at each source position using Equation (1) which is solved in the least squares sense with $p(\mathbf{k}, \omega) = e^{-j\mathbf{k}\mathbf{x}}$, the sensitivity functions are computed with the following equation:

$$H_v(\mathbf{x}, \mathbf{k}, \omega) = \sum_s Q_s(\mathbf{k}, \omega) H_{v/s}(\mathbf{x}, \omega) \quad (3)$$

3.2 Results

Figure 2 shows a comparison between the theoretical and experimental sensitivity functions. The source used for the experiment was only efficient from approximately 300 Hz to 7000 Hz: this is the reason the experimental sensitivity function do not exactly match the theoretical one below 300 Hz. Outside that frequency range and for the considered wavenumber domain, the results are in good agreement: the modal frequencies of the plate can be located around the flexural wavenumber where the response of the plate is maximum.

In Figure 3, the vibration response of the plate to a TBL excitation determined from vibration theory, anechoic wind tunnel measurements and the proposed approach are compared. The TBL

excitation parameters are taken from a previous paper [5]. In this study, the CSD function of the wall-pressure fluctuations was measured in the spatial-frequency domain and the parameters were adjusted to the TBL model of Mellen, the free stream velocity of the TBL was set at 20 m s^{-1} .

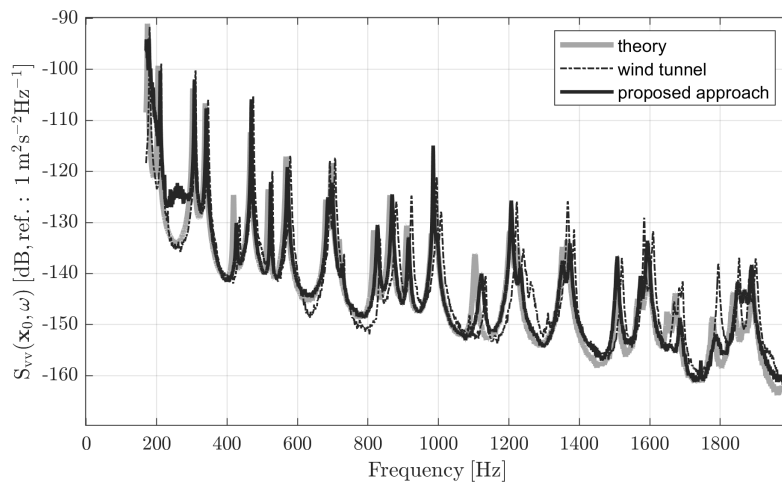


Figure 3. Vibration response of the plate at point $\mathbf{x} = (0.06 \text{ m}, 0.3 \text{ m})$.

As one can observe in Figure 3, the vibration response determined with the proposed approach does not match those obtained from the theory and the wind tunnel measurements under 300 Hz: this is due the fact that the source is not efficient in that frequency range as stated before. The vertical offsets that can be observed at some frequencies are due to the fact that for the theoretical and proposed approach cases, the modal damping of the plate is taken constant in the entire frequency range. As for the horizontal offset, it is certainly due to the difference of boundary conditions between the theory, where the boundary conditions are perfect, and the experimentations, where they are not and differ from one setup to another. Overall, the three results are in good agreement.

4 CONCLUSION

The results obtained with the proposed approach for the simulation of the TBL induced vibrations of a simple were compared to analytical results and those determined from anechoic wind tunnel measurements. This comparison shows good agreement and that the proposed method is promising.

ACKNOWLEDGMENTS

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