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Prediction of acoustic behaviour of microperforated plates in high-lift configuration

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Introduction

The reduction of aircraft noise is becoming important in the engineering field, due to the growth of urban center in the surroundings of existing airports. Very efficient low noise high lift devices and low noise propeller drives integration are keys to minimize the noise emissions. In an aircraft, high-lift system are the components that increase the lift during the take off and the flight. For example, the leading edge that is the front part of the wing and the trailing edge, the rear part of the wing and the propeller drives are the components that provide the propulsive force. As a part of the project *Sonderforschungsbereich 880* Fundamentals of High Lift for Future Civil Aircraft, our motivation is to reduce the sound produced by aircraft propeller drives and trailing edges. In order to reduce the flow noise and influence the structure-borne sound porous materials are used. The aim of this work is to implement in our in-House Code OptiSTA, a model to predict the behavior of microperforated plates. This model is based in the Johson-Allard for ridig frame porous media by Atalla and Sgard, and the transfer matrix method is used as the simulation method.

Modelling of Micro-perforated Plates

Perforated plates are used in different noise control applications. They can be classified in macro-perforated plates with perforation radius between 1 mm and 1 cm and micro-perforated plates with perforation radius smaller than 1mm. The effect and behaviour of the perforated plates are mainly dependent on the porosity, flow resistivity, perforation thickness and mounting condition. To model perforated plates, an approach based on the Johnson-Allard for ridig frame porous media by Atalla and Sgard is used. Biots parameters for cylindrical pores and an equivalent tortuosity are assumed [2]. The used mounting configuration is shown in Figure 1. The configuration consists of a perforated plate with thickness h, separated from a hard wall by an air cavity. For straight cylindrical pores the flow resistivity $\sigma = 8\eta/\phi r^2$, is related to the perforation radius of the pore r and the porosity ϕ, where η is the viscosity of air. The viscous and the thermal characteristics lengths, Λ and $\Lambda^{'}$, respectively, are equal to the hydraulic radius of the pore $\Lambda = \Lambda^{'} = \bar{r}$ [1]. In order to take into account the distortions of the flow induced by the perforations, the tortuosity of the perforated plates must be corrected depending on the media in which the perforated system radiates [2].

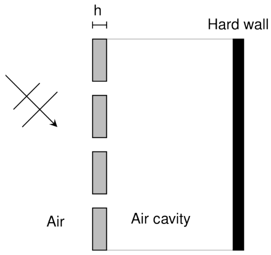

Figure 1: Mounting configuration. Perforated plate separated from a hard wall by an air cavity.

$$\alpha_\infty = 1 + \frac{2 \cdot \varepsilon_e}{h} \quad (1)$$

$$\varepsilon_e = 0.48\sqrt{\pi r^2}(1 - 1.14\sqrt{\phi}) \quad (2)$$

The correction term ε_e, is a function of the correction length asssociated the radiation of a circular piston in free air together with the tortuosity of the medium in which the perforated plate radiates [2].

Transfer Matrix Method

As a simulation method we use the transfer matrix method. The transfer matrix method is used in acoustics to analyze the transmission of acoustic waves through a layered medium, where the media is assumed laterally infinite. The components of the vector $V(M)$ are the variables which describes the acoustic field at the point M of the medium (3). The matrix T depends on the thickness h and the physical properties of each medium [1] [4].

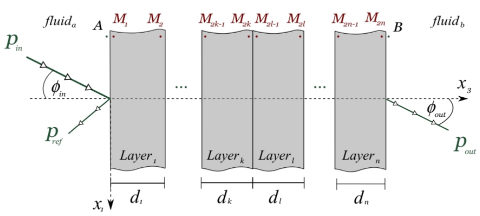

Figure 2: Transfer matrix method.

$$\mathbf{v}(M_{2k-1}) = \mathbf{T}\mathbf{v}(M_{2k}) \quad (3)$$

To model the perforated plate an effective density ρ_{eff} is used (4), where viscous and inertial effects are taken into account [2].

$$\rho_{eff} = \rho_0 \alpha_\infty (1 + \frac{\sigma\phi}{j\omega\rho_0\alpha_\infty} G_j(\omega)) \tag{4}$$

$$\text{where} \quad G_j(\omega) = \sqrt{1 + j\frac{4\omega\rho_0\alpha_\infty^2\eta}{\sigma^2\phi^2\Lambda^2}} \tag{5}$$

ρ_0 represents the air density and $j = \sqrt{-1}$. The sound absorption coefficient α can be predicted (6),

$$\alpha = \left| \frac{Z_A - \rho_0 c_0}{Z_A + \rho_0 c_0} \right|^2 . \tag{6}$$

Z_A denotes the impedance at the plate surface, c_0 the speed of sound and $Z_0 = \rho_0 c_0$ the impedance of the air.

$$Z_A = \left(\frac{2h}{r} + 4\frac{\varepsilon_e}{r}\right)\frac{R_s}{\phi} + \frac{1}{\phi}(2\varepsilon_e + h)j\omega\rho_0 - j\rho_0 c_0 \cot(k_0 L). \tag{7}$$

where κ is the wavenumber, L is the depth of the air cavity and R_s represents the surface resistance.

Verification and Validation

The configuration used to validate this work is the same used by Atalla and Sgard [2] and shown in Figure 1. A perforated plate with thickness of 1 mm and perforation radius 0.5 mm, backed by a 60 mm thick air cavity. The flow resistivity is equal to 23440 $N\,s\,m^{-4}$ and porosity 0.025. In Figure 3, the obtained results are represented with a black dashed line and they match with the work done by Atalla and Sgard in a solid red line. This graphic also shows that, the results of the model implemented in this work follow the same behaviour of the results obtained by other authors, (for example Maa and Beranek and Ingard). To validate the

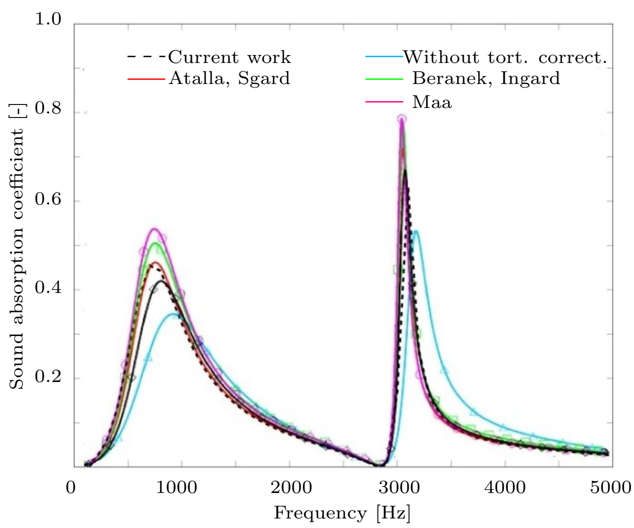

Figure 3: Verification of the implemented model using the configuration used by Atalla and Sgard.

implemented model, the sound absorption measurements of a perforated plate is used. The used mounting configuration is shown in Figure 1, with a plate thickness of 0.52 mm, pore radius of 0.03 mm, and air cavity of 20 mm. The flow resistivity is equal to 811558 $N\,s\,m^{-4}$ and porosity 0.135. Figure 4 shows in a solid black line the sound absorption measurements and in red line the results of the model implemented in our in-House Code Optista. The sound absorption results are in accordance with the sound aborption measurements.

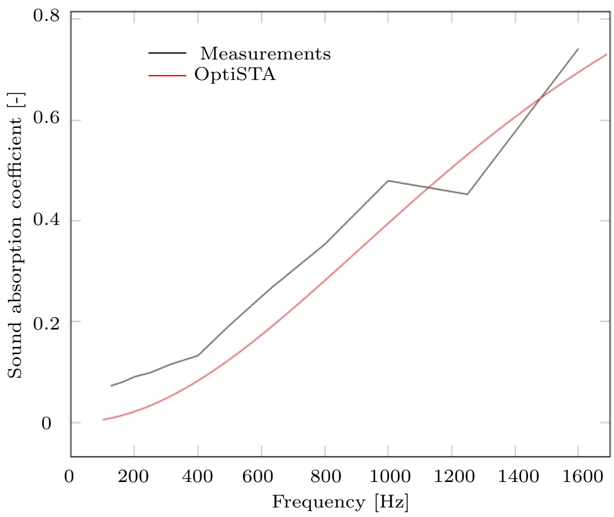

Figure 4: Validation of the implemented model using a perforated plate with circular cross section perforations.

Summary and Outlook

A perforated plate model based on the model proposed by Atalla and Sgard was implemented. This approach is based in the Johnson-Allard model for rigid porous media with an effective tortuosity. Next work is the implementation of a model to simulate various perforated plates configurations.

Acknowledgment

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